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13. ABSTRACT (Maximum 200 words)

This research examined the relation between implicit and explicit memory for novel visual objects. Implicit memory was assessed with an object decision task in which previously studied and nonstudied objects were flashed briefly and subjects decided whether they were structurally possible or impossible; implicit memory was indicated by more accurate object decision performance for studied than nonstudied objects (a priming effect). Explicit memory was assessed with a standard yes/no recognition task. Results of several experiments revealed: a) priming for possible but not impossible objects across a range of conditions and materials; b) invariance of priming across study/test changes of object size and reflection that impaired recognition; c) enhancement of recognition but not priming by functional encoding tasks; and d) preservation of object priming in amnesic patients with explicit memory deficits. Results suggest that priming is mediated by a presemantic structural description system that is independent of episodic memory.

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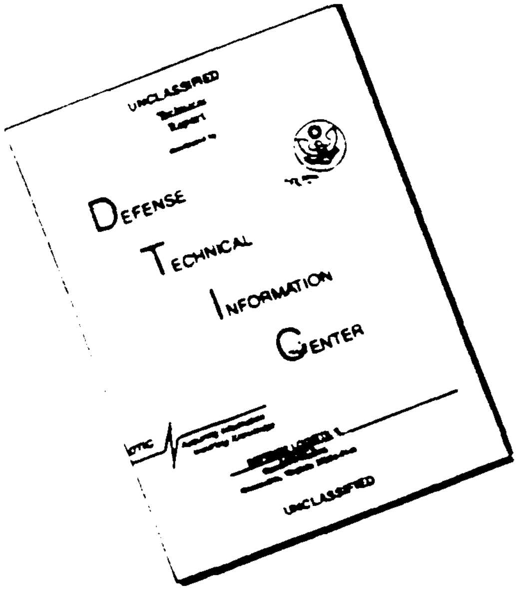

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Final Technical Report

AFOSR Grant "Forms of memory for representation of visual objects", 12/1/89-4/15/91
Daniel L. Schacter, Principal Investigator
Lynn A. Cooper, Co-Investigator

Objectives of the Research The main purpose of the research is to elucidate the processes and structures involved in explicit and implicit memory for visual objects. The major hypothesis under investigation is that implicit memory for visual objects, as indicated by priming effects on appropriate tests, is mediated by a presemantic structural description system, whereas explicit memory for visual objects depends on an episodic memory system. This hypothesis has been investigated primarily by comparing performance on an object decision test with performance on a yes/no recognition test On the object decision test, subjects decide whether briefly presented novel objects are structurally possible or impossible; implicit memory is inferred when subjects make more accurate object decisions about studied objects than about non-studied objects (i.e., a priming effect). On the yes/no recognition test, subjects attempt to remember explicitly whether they studied old and new objects. By comparing performance on these tasks across a range of experimental conditions and subject populations, the research should provide basic information about the mechanisms of visual object memory.

Status of the Research Effort Experiments that were completed or intitiated during the year of the grant can be partitioned into five categories, each of which are summarized in turn below.

Constraints on the construction of structural descriptions In several early experiments examining implicit memory on the object decision task, we found that priming was observed for possible objects but not for impossible objects. We argued that priming on the object decision task requires the construction of a representation that preserves three-dimensional information about global object structure, and that the structural description system involved in object decision priming cannot compute a global representation of an impossible object. However, a number of alternative interpretations of the data were also possible -- namely, that failure to observe priming of impossible objects was attributable to low levels of explicit memory, response requirements of the object decision task, or idiosyncratic features of target materials. Accordingly, we conducted a series of further studies during the first grant year that allowed us to reject these hypotheses (Schacter, Cooper, Delaney, Tharan, & Peterson, 1991). In addition, these experiments explored further the nature of structural descriptions involved in priming of possible objects, and revealed that a) such priming was observed with a 5-sec, but not a 1-sec, presentation rate during the study task, and b) priming did not increase with increasing numbers of study-list repetitions of target objects, whereas recognition memory was significantly improved by repetition. The enclosed reprint of the pertinent article describes the method, results, and implications in greater detail.

Nature of structural descriptions A major series of experiments was initiated to explore the nature of structural descriptions involved in object decision priming. In these experiments, we changed a particular attribute of target objects between study and test (e.g., the size of the object or its orientation), and assessed the effect of this change on object decision and recognition performance, respectively. The basic idea is that if study-to-test transformations modify or reduce the magnitude of priming or recognition effects, we can conclude that the underlying system accessed by the relevant memory task does represent the form of information in question. If, however, priming or recognition effects persist in the face of study-to-test changes in certain forms of information about objects, then we can infer that the representational system being tapped by the relevant memory test is not sensitive to the type of information undergoing change.

An initial experiment examined study/test changes in the size of target objects on priming and recognition performance (Cooper, Schacter, Ballesteros, & Moore, 1991). In this experiment, subjects encoded possible and impossible objects with the left/right study task used in previous studies. A between-subjects design was used such that for half the subjects, the studied objects were defined as "small" (8 deg of visual angle, on average), and for the other half of the subjects, the objects were

2.5 times larger. Size of objects was crossed between study and test to yield each of the four critical combinations of large/large, small/small, large/small, and small/large. The key finding was that object decision priming was unaffected by the size manipulation, whereas recognition performance was significantly lower when object size was changed between study and test than when it was held constant (see enclosed manuscript by Cooper et.al. for further details).

A second experiment used a similar logic and within-subjects design to examine sensitivity of the representations underlying implicit and explicit tests to changes in the parity or standard/reflected orientation of objects between study and test. Subjects studied sets of possible and impossible objects in an arbitrarily-selected standard orientation, and they were then tested with either standard views or mirror-image versions of the studied and non-studied objects. Although not quite as clear-cut as in the size experiment, results revealed that robust priming was observed in both the standard and mirror-image conditions, whereas recognition memory was greatly impaired by the parity change (see Cooper et.al. for further details). Thus, the data from these experiments suggest that a size and reflection invariant structural description subserves object decision priming, whereas the episodic representation of an object that subserves recognition memory includes both size and reflection information. These data are consistent with the idea that only information about relations among object parts are preserved in structural descriptions.

In a more recent set of experiments, we have employed a similar experimental design to investigate the effect of study/test changes in picture plane orientation. An initial experiment provided preliminary evidence that transformations of orientation within the plane significantly reduced performance on both object decision and recognition tests. However, the data were rather noisy, resulting from the within-subjects use of five picture plane orientations (in addition to the standard), and the attendant small numbers of observations per cell in the design. We then undertook a systematic replication using only three test orientations (illustrated in Figure 1), and increasing the numbers of observations per cell. Results were clear-cut: Substantial priming was obtained when studied and test objects were presented in the same picture-plane orientation, but priming was not observed when test orientation was changed. In line with our earlier findings, explicit recognition was impaired for orientation-transformed objects relative to objects shown in the same orientation at study and test. We have recently completed another experiment in this series, using only only a standard orientation and an orientation departing by 180 deg. Similar results to the previously described study were obtained.

The patterns of results observed in the foregoing studies raises an important question: How can we explain the specifcity of object decision priming to the picture plane orientation of target objects in light of the invariance of priming over changes in size and reflection? One conjecture that makes sense from our theoretical perspective is that structural descriptions of three-dimensional objects are axis-based and are computed relative to a frame of reference. That is, not only are relations among the components of an object themselves coded in such structural representations; in addition, the relations of these components to an object's major axis is also preserved. Adequate evaluation of this idea will require converging experimental work that will be carried out in the next year.

Relation between structural and functional encoding We have hypothesized that the structural description system operates at a presemantic level and does not handle information about the functional and associative properties of objects. To test and explore this idea, we initiated a series of experiments that examine the effects of various functional encoding tasks on object decision and recognition performance. In our first experiment, a functional encoding task (deciding whether an object could best be used as a tool or for support) was compared with a structural encoding task (deciding whether the object faces primarily to the left or to the right), using a between-subjects design. We expected that functional encoding would lead to higher recognition performance than would structural encoding, because in the former but not the latter condition, subjects presumably think of objects in a meaningful context and in relation to their pre-existing knowledge about objects and actions that can be performed with them. By contrast, we expected that functional encoding would not produce more priming than structural encoding, although we expected some priming in the functional condition, because subjects presumably need to encode object structure in order to make a judgment about object function.

Results of an initial experiment were consistent with these ideas:

significant priming of possible objects was observed following both encoding tasks, the magnitude of the effect did not differ between tasks, and no priming of impossible objects was observed following either task. By contrast, functional encoding produced much higher levels of recognition than did structural encoding, as reflected by a signficant interaction of encoding task x type of test. However, overall levels of object decision performance for studied possible objects were rather high in this experiment (over 80%), so the lack of an encoding task effect on priming could be attrributable to ceiling effects. To address the issue, we conducted an additional experiment in which we lowered object decision performance by shortening the exposure duration on the object decision test from 100 ms to 50 ms. Under these conditions, performance was well below ceiling levels, but the same patterns of results was obtained: Type of encoding task had no effect on priming and a large effect on recognition.

Additional studies in this series examined the relation between object structure and function. In the tool/support encoding task, structural properties of the object directly constrain the type of function for which they are best suited -- that is, the structural features of the object directly determine whether subjects decide that it could be used best as a tool or for support. The question we attempted to answer is whether such direct constraint is necessary in order to observe signficant priming following functional encoding. By our view, priming is observed following functional encoding because making a functional judgment requires or entails structural analysis. However, the exact relation between structure and function should not be important: Information about object function is presumably represented outside of the structural description system. Accordingly, we would expect priming to occur whether or not object structure directly constrains object function. To address the issue, we compared an encoding task in which structure directly constrains function (deciding whether each object was best suited to store things inside of or put things on top of), and an encoding task in which function is not directly constrained by structure (subjects were asked to imagine what type of sound each object would make). Consistent with predictions, significant and equivalent levels of priming were observed following each encoding task.

The foregoing pattern of results suggests that priming is observed following functional encoding tasks because subjects base their functional judgments on object structure, whether or not such structure directly constrains function. Information about functional attributes, however, is handled and stored outside of the structural description system, presumably by episodic memory. In ongoing research, we are further addressing the structure/function issue by examining the effects of combining structural and functional encoding tasks in different ways.

Studies of populations with memory disorders If object decision priming depends on a structural description system that is independent of the episodic memory system, then priming ought to be preserved in subjects who are characterized by episodic memory deficits. We have conducted two studies that provide pertinent evidence. In one experiment, we examined the performance of brain-damaged patients with memory disorders. Object decision and recognition performance (following the left/right encoding task) in six amnesic patients was compared with the performance of six matched controls and six student controls. Results indicated that amnesic patients showed significant -- and most importantly, normal -- priming effects relative to control subjects. However, the amnesics were impaired signficantly on the recognition memory task (for details, see enclosed paper by Schacter, Cooper, Tharan, & Rubens, in press, 1991). These dissociations have led us to argue that object decision priming is likely mediated by brain systems that are independent of the limbic structures that are necessary for explicit remembering. We have suggested that priming probably depends to a large extent on regions of inferior temporal cortex, which have been implicated on independent grounds in the storage of size- and reflection-invariant object representations and are generally spared in amnesic patients.

Research in progress is examining whether object decision priming is spared in elderly adults with explicit memory deficits.

Methodological advances In addition to the studies outlined above, we have also made progress in developing our materials and tasks. We have enlarged our set of possible and impossible objects from 40 to 80. This has been a time consuming process that required extensive pilot work comprised of three stages: 1) producing new drawings of candidate possible and impossible objects (a task accomplished by graduate assistant Suzanne Delaney); 2) determining that when given unlimited viewing time, subjects show 95% or better agreement that objects are possible or impossible; and 3) determining that subjects make about 60% correct object decisions about these same drawings when they are exposed for 50 msec. Despite the fact that nearly 9 months was needed to fulfill these requirements for 40 new objects (20 possible and 20 impossible), the enlarged object set will allow us greater flexibility in our future studies. In addition, we have developed new, more naturalistic versions of our objects (see Figure 2) Specifically, we have used the Silicon Graphics Personal IRIS computer facility available in Cooper's laboratory to develop object stimuli that are rendered as solid, textured, colored, depth-cued three-dimensional objects. This new object set consists solely of possible objects, because impossible objects cannot, by definition, be rendered in this manner. Although construction of these objects demanded considerable time during the award year, their availability sets the stage for a variety of novel studies that we will pursue in coming years.

The depth-cued objects will be used initially in a new task that we have developed and for assessing object priming -- a symmetry judgment task in which subjects decide whether objects are symmetrical or asymmetrical. Use of the symmetry judgment task will make it possible to examine effects of rotation-in-depth on priming and recognition of novel objects (impossible objects cannot be rotated in depth), and will also allow us to provide converging evidence on the various theoretical hypotheses discussed above. We are also developing two tasks for studying priming of familiar objects: an object completion task, in which subjects study pictures of familiar objects and later complete fragments of them with the first object that comes to mind; and an object identification task in which subjects attempt to identify briefly presented pictures of studied and nonstudied familiar objects. Studies using these tasks should contribute to enhancing the breadth of our research and theoretical conclusions.

List of publications in technical journals

Cooper, L.A., Schacter, D.L., Ballesteros, S., & Moore, C. Priming and recognition of transformed three-dimensional objects. Submitted to Journal of Experimental Psychology: Learning, Memory, & Cognition.

Schacter, D.L. (1990). Perceptual representations systems and implicit memory: Toward a resolution of the multiple memory systems debtate. Annals of the New York Academy of Sciences, 608, 543-571.

Schacter, D.L., Cooper, L.A., & Delaney, S.M. (1990). Implicit memory for visual objects and the structural description system. Bulletin of the Psychonomic Society, 28, 367-372.

Schacter, D.L., Cooper, L.A., Delaney, S.M., Peterson, M.A., & Tharan, M. (1991). Implicit memory for possible and impossible objects: Constraints on the construction of structural descriptions. Journal of Experimental Psychology: Learning, Memory, & Cognition, 17, 3-19.

Schacter, D.L., Cooper, L.A., Tharan, M., & Rubens, A.B. (in press, 1991). Preserved priming of novel objects in patients with memory disorders. Journal of Cognitive Neuroscience.

Schacter, D.L., Delaney, S.M., & Merikle, E.P. (1990). Priming of nonverbal information and the nature of implicit memory. The Psychology of Learning and Motivation, 26, 83-123.

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MA thesis: Suzanne M. Delaney, "Implicit and explicit memory for novel visual objects".

Papers presented at professional meetings

Cooper, L.A. (1990, June). Mental representation of novel three-dimensional objects. Presented to Annual Meeting of the International Neuropsychological Symposium, Athens, Greece.

Cooper, L.A. (1990, August). Priming and recognition of novel objects. Presented to Third International Conference on Imagery, Aberdeen, Scotland.

Cooper, L.A., Schacter, D.L., Ballesteros, S., & Moore, C. (1990. November). Priming of structural representations of three-dimensional objects. Presented to Annual Meeting of the Psychonomic Society, New Orleans.

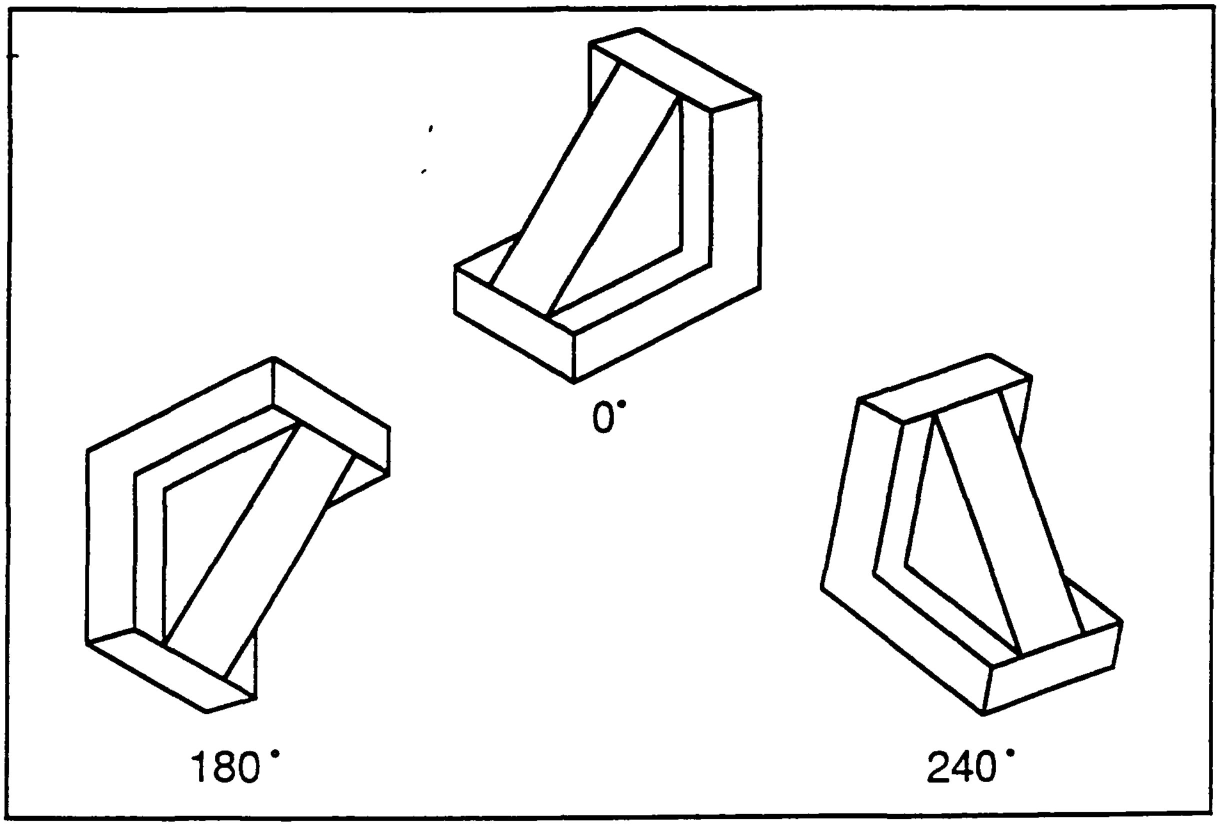
Schacter, D.L. (1990, April). Cognitive and neuropsychological perspectives on priming. Presented to Annual Meeting of Southeastern Workers in Memory, Atlanta.

Schacter, D.L. (1990, May). Priming of novel objects and perceptual representation systems. Presented to Annual Meeting of the European Brain and Behavior Conference, Padua, Italy.

Schacter, D.L. (1990, June). Implicit memory and the brain. Presented to President's Symposium on Memory, Annual Meeting of the American Psychological Society, Dallas.

Schacter, D.L. (1990, October). Object priming and memory systems. Presented to Annual Meeting of the Memory Disorders Research Society, Boston.

Figure 1



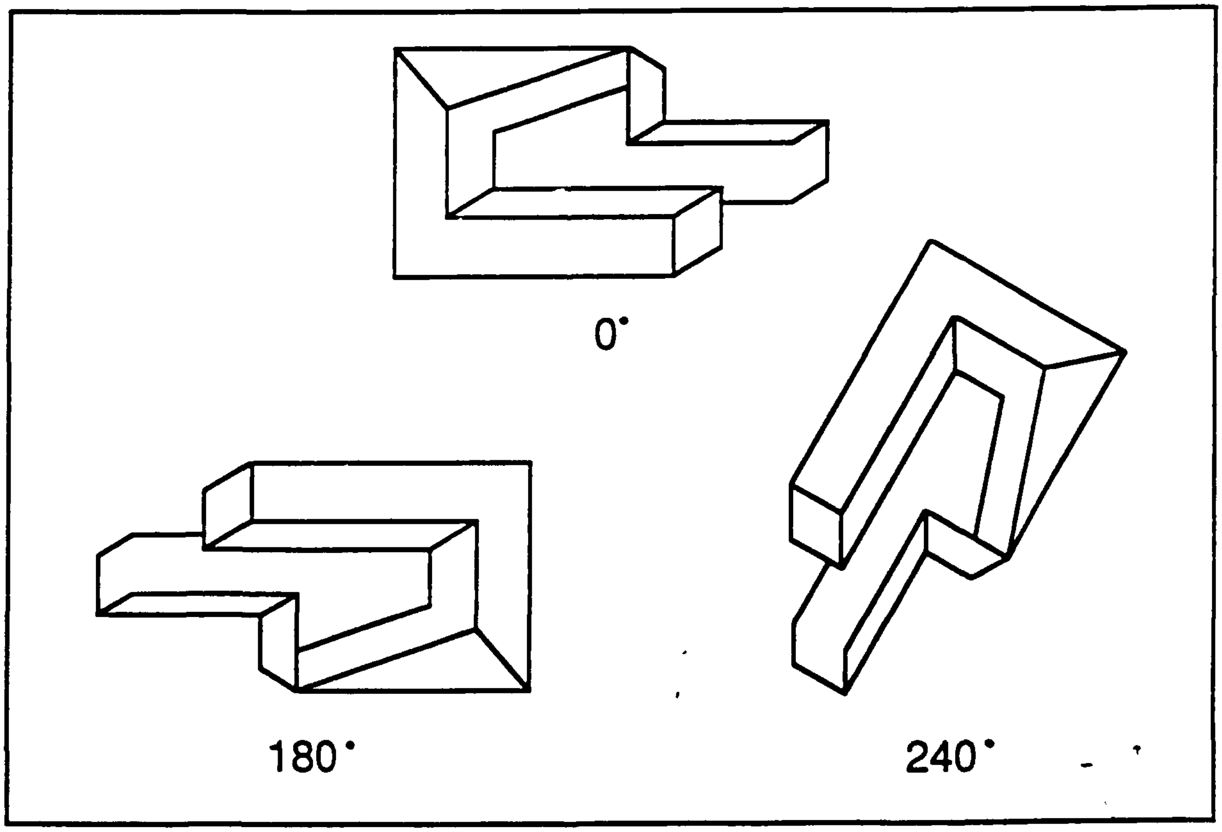
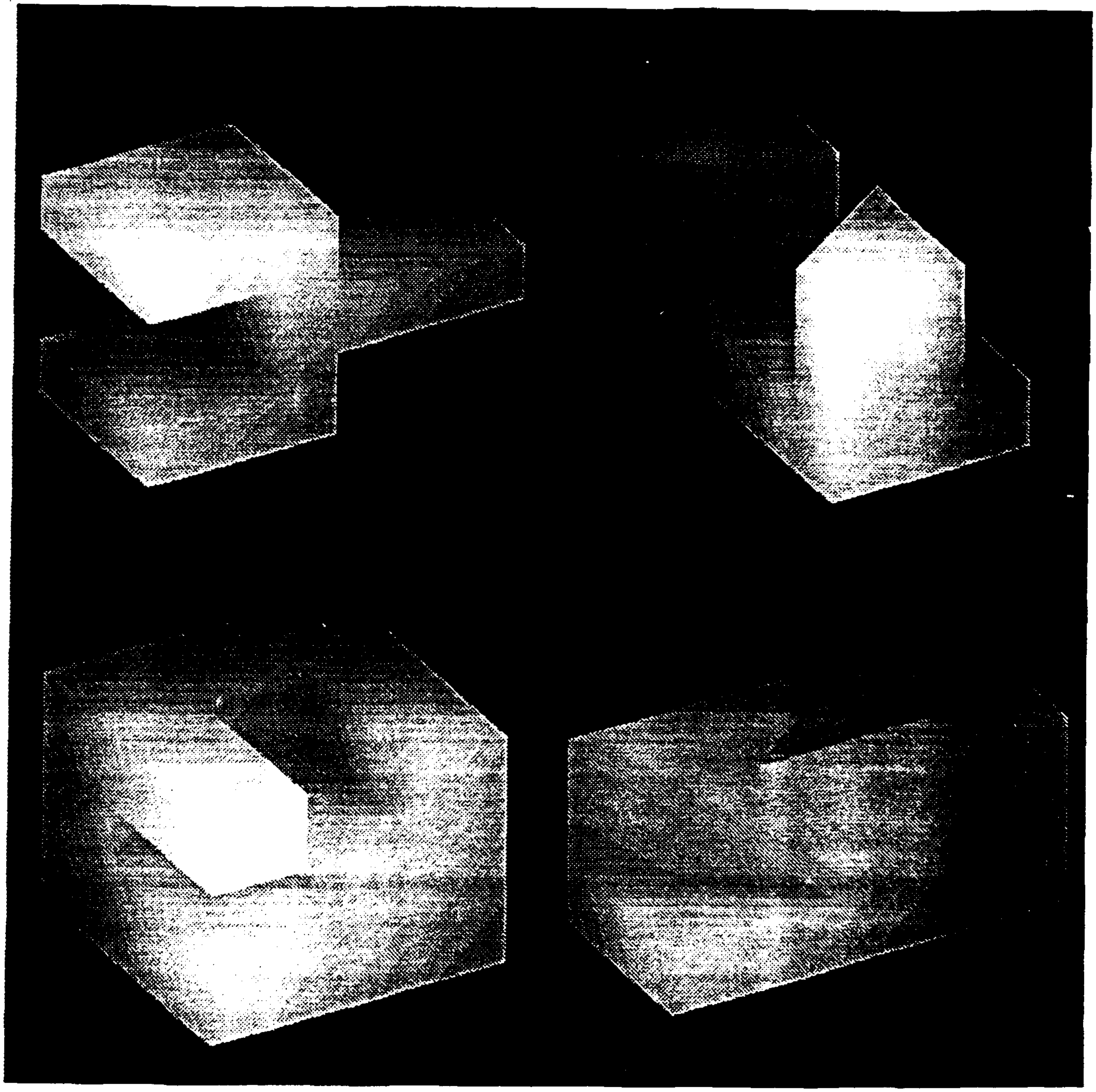


Figure 2



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Final Technical Report

AFOSR Grant "Forms of memory for representation of visual objects",
12/1/89-4/15/91

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Perceptual Representation Systems and Implicit Memory

Toward a Resolution of the Multiple Memory Systems Debate[a]

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Consider the following experimental situations. In the first, subjects are shown a list of familiar words and are instructed to carefully study each of them. After performing a variety of unrelated tasks for several minutes, they are told to think back to the study list and recall as many of the presented words as possible. Subjects are then shown a series of words—half were presented in the study list, half were not—and are instructed to say "yes" if they remember having studied the items, and "no" if they do not remember them. In the second situation, subjects also study a word list and then engage in unrelated activities for a few minutes. However, instead of then being asked to remember previously studied items, the subjects are asked to write down the first word that comes to mind in response to a series of 3-letter word stems; some can be completed with previously studied words, and some cannot.

The first of these two hypothetical situations reflects the way in which cognitive psychologists have traditionally studied human memory: by assessing subjects' intentional or *explicit memory* for information acquired during a study episode with standard recall and recognition tests. In the second situation, memory is inferred from an enhanced tendency to complete 3-letter stems with previously studied words; this is often referred to as "repetition priming" or "direct priming" (cf., Cofer, 1967; Tulving & Schacter, 1990). Priming effects need not and often do not involve any conscious or explicit recollection of a prior episode, and thus can be said to reflect *implicit memory* for previously studied information (Graf & Schacter, 1985; Schacter, 1987).

Priming has been assessed with a variety of implicit memory tasks that do not require explicit recollection of a specific prior episode. One common type of implicit test involves completing word stems or word fragments with the first word that comes to mind, as in the foregoing example (e.g., Graf & Mandler, 1984; Light, Singh & Capps, 1986; Roediger & Blaxton, 1987a, b; Schacter & Graf, 1986a, b; Tulving, Schacter & Stark, 1982). Another frequently used implicit task involves word identification: Subjects are required to try to identify a word from a brief (e.g., 50-msec) perceptual exposure, and priming is indicated by more accurate identification of a recently studied item than of a new, nonstudied item (e.g., Jacoby, 1983a, b;

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Jacoby & Dallas, 1981; Light & Singh, 1987; Winnick & Daniel, 1970). Similar completion and identification tasks have been used to assess priming of nonverbal information, such as pictures of familiar objects: Subjects are required to complete fragmented pictures by indicating what object the fragment represents, or are required to identify an object from a brief exposure (e.g., Mitchell & Brown, 1988; Snodgrass, 1989; Weldon & Roediger, 1987). Priming has also been assessed with the lexical decision task, where subjects decide whether a string of letters represents a real word or nonword; priming is indicated when subjects make lexical decisions more quickly for recently studied words or recently studied nonwords than for new words or new nonwords that were not previously presented in the experiment (e.g., Kirsner, Milech & Standen, 1983; Scarborough, Gerard & Cortese, 1979).

Although the exact requirements of the various implicit tasks that are used to assess priming differ from one another, priming is generally said to occur if the probability of identifying previously studied items is increased, or the latency of an identification response is decreased, relative to similar measures for nonstudied items. The magnitude of priming, then, is indicated by the size of the difference between accuracy or latency of response to studied items and accuracy or latency of response to nonstudied items.

The most striking outcome of recent priming studies is that implicit and explicit memory can be sharply dissociated: Several experimental variables affect the two forms of memory differently, and subject populations that are characterized by impaired explicit memory exhibit intact priming or implicit memory (see below for examples; for extensive reviews, see Richardson-Klavehn & Bjork, 1988; Schacter, 1987). The existence of such dissociations, together with the observations of parallels between implicit and explicit memory in some situations, has led to extensive theoretical discussion concerning the underlying bases of implicit and explicit memory. In particular, there has been heated debate as to whether the data necessitate the postulation of different memory systems underlying implicit and explicit memory, or whether the results can be more usefully conceptualized in terms of different processes operating within a unitary system (cf., Cohen, 1984; Hayman & Tulving, 1989; Jacoby, 1983a, b; Moscovitch, Winocur & McLachlan, 1986; Roediger *et al.*, this volume; Roediger & Blaxon, 1987a; Schacter, 1987; Schacter & Moscovitch, 1984; Sherry & Schacter, 1987; Tulving, 1983; Tulving *et al.*, 1982).

The purpose of the present article is to put forward a possible resolution to the multiple memory systems debate. The suggested resolution accommodates some of the main points put forward by unitary system, process-oriented theorists, yet also argues for the usefulness of postulating entities that can be broadly conceived of as multiple memory systems, and is thus in the general spirit of other recent attempts to integrate the two approaches (cf., Hayman & Tulving, 1989). More specifically, I will propose that priming effects on a variety of implicit memory tests rely heavily on a class of modular processors or subsystems that have been identified in recent research by cognitive neuropsychologists and that together form what I will refer to as a *perceptual representation system*, or PRS for short (see also, Schacter, Cooper & Delaney, 1990a, 1990b; Schacter, Delaney & Merikle, in press; Tulving & Schacter, 1990). These subsystems have been described in various sectors of neuropsychological research (Ellis & Young, 1988; Morton & Patterson, 1980; Riddoch, Humphreys, Coltheart & Funnell, 1988), but I will focus largely on studies of reading disorders (i.e., alexia) and perceptual dysfunctions (i.e., agnosia). Observations from these patient populations have not been previously brought to bear on, or thought of as related to, implicit memory research. By the present view, however, data from alexic, agnosic, and other patients in which PRS is either spared or impaired can provide important clues concerning the nature and architecture of the systems that play an important role in implicit memory.

The paper consists of four main sections: (1) a brief overview of some key dissociations observed in studies of implicit memory for verbal materials that suggest that priming is a presemantic phenomenon, (2) an attempt to relate these dissociations to observations concerning patients with acquired reading disorders (alexia) and (3) object-processing disorders (agnosia) that provide the central motivation for the PRS hypothesis, and (4) a summary of some recent research from my laboratory concerning nonverbal implicit memory that provides a link to the agnosia data and empirical support for the proposed ideas.

PRIMING: A PRESEMANTIC PHENOMENON

A number of experimental manipulations have produced implicit/explicit dissociations and delineated various features of priming (see Richardson-Klavehn & Bjork, 1988; Schacter, 1987). For purposes of this discussion, I focus on one aspect of priming on various implicit memory tests that distinguishes it from explicit memory: Priming appears to be a *presemantic* phenomenon, in the sense that (a) it occurs whether or not subjects perform semantic encoding operations, and (b) it is quite sensitive to changes in perceptual properties of target information. Explicit memory, on the other hand, is generally dependent on, and greatly enhanced by, semantic encoding operations and is less sensitive to changes in perceptual properties of target information.

Consider first the evidence concerning the effects of semantic encoding on implicit and explicit memory. It has been known since the classic studies of Craik and others in the 1970s (e.g., Craik & Tulving, 1975) that performance on standard recall and recognition tests is significantly higher following semantic study than following nonsemantic study of to-be-remembered information. Thus, for example, when subjects are given a semantic encoding task (e.g., to rate the pleasantness of a word, answer a question about its meaning, and so on) subsequent probability of explicitly remembering the word is generally much higher than if subjects perform a nonsemantic or structural encoding task at the time of study (e.g., counting the number of vowels or consonants in the word). By contrast, several studies have shown that priming effects of similar magnitude are observed following semantic and nonsemantic study tasks.

In an experiment by Jacoby and Dallas (1981), for instance, study processing was manipulated by having subjects either answer questions about the meaning of target words or decide whether or not a word contained a particular letter. Explicit memory was then assessed with a yes/no recognition test, and implicit memory was assessed with a word identification task in which subjects attempted to identify previously studied words and new words from a brief exposure. Priming on the latter task is indicated when subjects identify more studied than nonstudied words. Jacoby and

Dallas (1981) found significant priming on the word identification test, and most important, observed that the magnitude of the effect was the same following the semantic and nonsemantic study tasks. Recognition memory, by contrast, was considerably more accurate following semantic than nonsemantic encoding.

Graf and Mandler (1984) observed a similar pattern of results with different implicit and explicit memory tests. On a stem completion test in which subjects wrote down the first word that came to mind in response to 3-letter cues, priming effects were just as large following semantic and nonsemantic study tasks; however, explicit recall of studied words was significantly higher following semantic than nonsemantic encoding. Similar patterns of results have been reported in other studies that have compared priming effects on completion and identificatioin tasks with explicit recall and recognition performance (e.g., Graf, Mandler & Haden, 1982; Jacoby, 1983a, b; Roediger & Blaxton, 1987a; Winnick & Daniel, 1970). Note, however, that some forms of semantic study processing do facilitate implicit memory performance in certain situations (e.g., Graf & Schacter, 1985; Masson, 1989; Schacter & Graf, 1986a, b); this is an important point that I will return to later.

A second key observation is that changing various kinds of surface features of to-be-remembered items between study and test impairs performance on implicit tests more than on explicit tests. Several different types of evidence bear on this general point. The first and perhaps most firmly established finding is that a study/test shift in sensory modality—that is, presenting the material in one modality and testing it in another—either reduces or eliminates priming. This phenomenon has been observed both with shifts from auditory study (i.e., hearing the word) to visual test (i.e., seeing the word; e.g., Graf, Shimamura & Squire, 1985; Jacoby & Dallas, 1981; Kirsner, Milech & Standen, 1983; Morton, 1979; Roediger & Blaxton, 1987a, b; Schacter & Graf, 1989) and from visual study to auditory test (e.g., Jackson & Morton, 1984).

In addition to modality effects, study/test changes in at least three types of surface feature information *within* the visual modality appear to impair performance on implicit tests while having less effect, or in some cases opposite effects, on explicit recall and recognition. First, several experiments have shown that when target items are presented for study in pictorial form (e.g., a drawing of a chair), priming effects on a variety of implicit tests—including lexical decision (Scarborough, Gerard & Cortese, 1979), word identification (Durso & Johnson, 1979; Kirsner, Milech & Stumpfl, 1986; Winnick & Daniel, 1970), and fragment completion (Weldon & Roediger, 1987)—are either entirely absent or significantly reduced relative to conditions in which the word itself is presented for study. By contrast, explicit remembering of words is enhanced by pictoral presentation relative to verbal presentation (Weldon & Roediger, 1987). Second, studies of bilingual subjects have shown that when words that have been studied in one language are then tested in another language on identification, completion, or lexical decision tasks, priming effects are severely reduced relative to when the words are presented in the same language at study and test (e.g., Durgunoglu & Roediger, 1987; Kirsner, Smith, Lockhart, King & Jain, 1984; for more detailed discussion, see Kirsner & Dunn, 1985; Roediger & Blaxton, 1987b).

Third, a number of studies have shown that priming can be reduced even by changes in the specific physical format of a word. Thus, for example, Roediger and

Blaxton (1987a) found that priming effects on a fragment completion test were smaller when target items that had been studied in handwritten form were subsequently tested in typed form than when they were tested in handwritten form. Jacoby and Hayman (1987) reported that study/test changes in typeface reduced priming on a word identification test. Recent studies using the fragment completion test have shown that even small changes in certain aspects of word orthography can have a dramatic impact on priming (see Gardiner, Dawson & Sutton, 1989; Hayman & Tulving, 1989). However, other studies have failed to find evidence of such format specific effects (e.g., Carr, Brown & Charalambous, 1989; Tardif & Craik, 1989). Recent experiments by Graf and Ryan (in press) suggest that priming is reduced by study/test changes in the precise physical format of a word when unusual typefonts are used and when subjects focus on the physical appearance of a word at the time of study.

Although a number of questions remain to be resolved concerning the role of semantic and structural factors in priming, two relatively unambiguous points emerge from the foregoing studies: (1) robust priming occurs on word completion and word identification tests following study tasks that do not require any semantic processing; (2) priming effects on these and other implicit memory tests depend critically on reinstating information about the perceptual form of target items.

THEORETICAL ACCOUNTS OF SEMANTIC AND SURFACE FEATURE DISSOCIATIONS

How can we account for the finding that performance on most implicit tests is independent of semantic vs. nonsemantic processing during study and is highly dependent on surface feature information, whereas performance on most explicit tests is dependent on semantic processing and less affected by surface feature manipulations? Schacter (1987) has delineated three classes of explanations for these and other implicit/explicit dissociations: activation, multiple memory systems, and processing accounts. For purpose of this discussion, I will focus on just one type of activation view, most prominently associated with Morton (1979), that can be considered as a subclass of the multiple memory systems explanation. Processing views will be considered as examples of a unitary memory system account.

Multiple Memory System Views

One of the earliest accounts of repetition priming effects was derived from Morton's (1969) logogen model. Logogens, according to Morton's initial formulation, are modality-independent, abstract lexical units that can be activated by presentation of a word. The logogen's threshold for firing is lowered temporarily by such activation; hence presentation of a word makes it easier to detect that word on a subsequent identification test. This model, however, was unable to accommodate modality-specific priming effects, so Morton (1979) revised it by postulating the existence of separate visual and auditory input logogen systems: The former contains a representation of the visual form of a word, the latter of its spoken form. Since written presentation of a word activates only the visual input logogen, and the spoken presentation activates only the auditory input logogen, modality-specific priming effects can be accommodated. Both visual and auditory logogens are held to be independent of a "cognitive system" that is involved in semantic processing and, presumably, in explicit or episodic remembering. Thus, the visual and auditory input logogens can in some sense be thought of as separate memory systems that represent modality-specific lexical information.

Although the foregoing account can handle results on modality-specific priming, it has considerable difficulty explaining the finding that *within* the visual modality priming effects are disrupted by study/test changes in the surface features of words. The logogen is held to be a pre-existing, abstract representation of the visual form of a word; therefore, the specific manner in which the word is presented should not influence logogen activation. Priming effects thus ought to be invariant across changes in surface feature information. But, as discussed above, priming is often quite sensitive to such changes (cf., Jacoby, 1983b; Roediger & Blaxton, 1987b). Another problem with this view is that priming effects on various implicit tests can last a long time—hours, days, weeks, and even years (e.g., Jacoby, 1983a; Mitchell & Brown, 1988; Sloman, Hayman, Ohta & Tulving, 1988; Tulving *et al.*, 1982)—whereas logogen activation is thought to decay within seconds or minutes (cf., Jacoby, 1983a; Roediger & Blaxton, 1987b; Schacter, 1987).

I have discussed the logogen view in some detail in order to highlight that its main difficulties as a general account of implicit memory phenomena stem from the model's failure to accommodate the *specificity* and *temporal persistence* of some priming phenomena. I will suggest later, however, that other aspects of this model can be useful for conceptualizing the underlying bases of implicit memory phenomena.

Other, rather different, multiple memory system accounts have also been put forward. Thus, for example, several investigators have argued that various implicit memory phenomena reflect the operation of a procedural memory system (or systems) that differs fundamentally from the declarative system involved in explicit remembering: implicit memory effects are thought to reflect on-line modifications of encoding procedures or operations, whereas explicit remembering depends on representations of the outcome of those procedures (cf., Cohen 1984; Squire, 1987). It has also been suggested that priming effects reflect the operations of a "quasi-memory system" that does not operate on focal memory traces or representations (Hayman & Tulving, 1989; Tulving, 1983, 1985). These and other multiple memory system accounts (cf., Johnson, 1983; Mitchell & Brown, 1988; Sherry & Schacter, 1987) cite data on experimental dissociations between implicit and explicit memory in normal subjects as well as demonstrations of preserved implicit memory in amnesic patients to support the claim of multiple memory systems (see Sherry & Schacter, 1987; Squire, 1987; Tulving, 1985).

Processing Views

In contrast to the foregoing, processing views maintain that both implicit and explicit remembering are based on newly created episodic representations within a unitary memory system. Experimental dissociations between implicit and explicit memory are viewed as special cases of the general principles of encoding specificity and transfer appropriate processing, which state that memory performance is determined by the degree of overlap or match between encoded attributes of memory representations and the processing demands of a memory test (e.g., Jacoby, 1983b; Masson, 1989; Roediger & Blaxton, 1987b; Roediger, Weldon & Challis, 1989; Witherspoon & Moscovitch, 1989). To accommodate the data on the differential effects of semantic versus surface feature processing on implicit and explicit tests, the distinction between data-driven and conceptually driven processing has been invoked (Jacoby, 1983b; Roediger & Blaxton, 1987a, b). By this view, most of the standard explicit memory tests require a good deal of *conceptually driven* processing: semantically based, subject-initiated reconstructive retrieval activity. In contrast, performance on such implicit tests as word identification, and stem and fragment completion, is largely *data driven;* that is, processing is determined largely by the physical characteristics of test cues. Accordingly, it follows that explicit but not implicit memory should benefit from semantic study processing (which is thought to support conceptually driven processing), whereas implicit but not explicit memory should be strongly dependent on matching of surface features between study and test (for more detailed discussion, see Masson, 1989; Richardson-Klavehn & Bjork, 1988; Roediger *et al.*, 1989; Schacter, 1987)

Problems with Existing Views

Both multiple memory system and processing views can account for many of the key empirical findings, but both have their drawbacks (Schacter, 1987). The main problems with multiple memory system accounts, according to processing theorists, are that (a) postulation of separate systems is not necessary to account for the data, and (b) simply identifying a task with a particular system does not illuminate the nature of the phenomenon in any interesting way. In addition, relatively little has been said by multiple system theorists about the *functions* of the system alleged to underly priming effects on implicit tests. Sherry and Schacter (1987) have argued that postulation of multiple memory systems is justified when a case can be made that the two putative systems perform distinct and incompatible functions—a condition that they referred to as *functional incompatibility* between systems. Sherry and Schacter contended that functional (as well as empirical) considerations support a distinction between a system involved in incremental habit/skill learning and a system underlying explicit recall and recognition. However, functional considerations have for the most part not been brought to bear on the question of whether single-trial priming effects on implicit tasks are mediated by a different system from the one involved in explicit, episodic remembering.

A major problem with most processing views is that they do not provide a satisfying account of why implicit memory is often preserved in severely amnesic patients (cf., Hayman & Tulving, 1989). This problem is particularly important because the finding that amnesic patients show normal priming on a variety of implicit tests—despite their poor performance on explicit tests of recall or recognition or their frequent inability to remember the study episode itself (e.g., Graf *et al.*, 1985; Schacter, 1985; Warrington & Weiskrantz, 1974)—probably constitutes the single most important basis for the distinction between implicit and explicit memory.

One possibility would be that amnesic patients are deficient in their ability to engage in conceptually driven processing. However, there is no evidence to support this view, and since most amnesic patients exhibit normal intellectual functions (and some patients who show robust priming effects possess superior intelligence [Cermak, Bleich & Blackford, 1988]) this possibility seems unlikely. Moreover, amnesic patients show intact priming effects on implicit tests that would appear to involve a great deal of conceptually driven processing, such as category instance production (Gardner, Boller, Moreines & Butters, 1973; Graf *et al.*, 1985) and free association (Schacter, 1985; Shimamura & Squire, 1984). A satisfying account of implicit memory phenomena ought to accommodate data from both normal and amnesic subjects.

PRS AND IMPLICIT MEMORY PHENOMENA

In this section I sketch a theoretical framework that incorporates aspects of both the processing and multiple memory system views. The key idea motivating this framework is that a class of modular subsystems, which together form what I have referred to as PRS, are critically involved in priming effects that are observed on many (though not all) implicit tests. An important feature of these subsystems, and PRS more generally, is that they process and represent information about the *form* and *structure* of words, objects, and other kinds of stimuli, but do not represent *semantic* or *associative* information about them (e.g., Ellis & Young, 1988; Riddoch *et al.*, 1988; Warrington & Shallice, 1980). PRS does, however, have connections with semantic and other systems. In this respect, the notion of PRS is similar to the logogen systems discussed by Morton (1979). As noted earlier, however, a logogen view does not provide a satisfactory account of the specificity and temporal persistence of implicit memory phenomena. If, however, we assert that priming is not based solely on the temporary activation of some old, abstract unit in the logogen system and argue instead that priming often reflects the establishment of new and highly specific representations within a particular perceptual system, these problems can be circumvented easily. To provide a fuller analysis of these ideas, let us turn first to research concerning acquired reading disorders for evidence concerning the nature of PRS.

Reading Disorders and the Word Form System

Research concerning reading disorders constitutes one of the most active areas of cognitive neuropsychology (for reviews, see Coltheart, Patterson & Marshall, 1980; Coltheart, Sartori & Job, 1987; Ellis & Young, 1988). A wide variety of classes and subclasses of deficits have been identified, but two types of patients are particularly relevant to the present concerns. Consider first a patient described by Schwartz, Saffran, and Marin (1980), who was unable to gain access to the meaning of words that were presented to her. Thus, for example, the patient could not classify words into semantic categories nor could she match a word to its pictorial equivalent. Yet despite her inability to understand the meaning of printed words, the patient could read them aloud quite accurately. Most important, this patient was able to read *irregular* words accurately (e.g., *blood, climb, gone*). The ability to read irregular words indicates that the patient had access to a stored representation of the word's visual form, because irregular words (unlike regular words) cannot be read on the basis of grapheme-to-phoneme conversion. Therefore, this case can be interpreted as demonstrating a dissociation between representations of the visual form of a word and the meaning of that word. Similarly, Funnell (1983) described a study in which the patient was unable to make semantic relatedness judgments about familiar words that she could read aloud. In addition, the patient could not read aloud pronounceable non-words (e.g., *blik*), thereby indicating that her reading of familiar words was not based on grapheme-to-phoneme conversion strategies. Sartori, Masterson, and Job (1987) studied a similar patient who could read aloud familiar words but could not sort these words into appropriate semantic categories; as in Funnell's (1983) case, the ability to read non-words was severely impaired.

These findings provide support for the idea that information about the visual form of a word is represented by a different system or subsystem than the one that handles semantic information about the word. An argument for a similar distinction has been made within the auditory domain on the basis of observations with a different set of patients (see Ellis & Young, 1988, Chapter 6). Warrington and Shallice (1980) have referred to the visually based system as the *visual word form system*, and I will adopt their terminology here. In the present scheme, the word form system is viewed as a component subsystem of PRS that deals with the visual form and structure of words, just as other component subsystems of PRS deal with other kinds of form and structure information, as will be discussed shortly.

Several cases have been reported that indicate that the word form system can be damaged selectively. Thus, for example, patients with surface dyslexia rely on grapheme-to-phoneme conversion strategies and read irregular words as if they were regular (e.g., *trough* is read as "truff"). These regularization errors suggest that a stored representation of the visual word form either has been lost or is inaccessible, and thereby imply damage to some aspect of the word form system (e.g., Marshall & Newcombe, 1973; Shallice, Warrington & McCarthy, 1983).

In addition to data from neuropsychological studies of patients with reading disorders, converging evidence for the existence of a visual word form system has been provided by research using positron emission tomography (PET). Petersen, Fox, Posner, Mintum, and Raichle (1988) have shown that simple reading of familiar words selectively activates regions of occipital cortex, whereas semantic processing of the words selectively activates more anterior regions of the left hemisphere. Petersen *et al.* argue on the basis of their data for a distinction between a visual word form system on the one hand and a semantic association system on the other (see also Posner, Peterson, Fox & Raichle, 1988).

Given these independent lines of evidence for the existence of a system that processes and represents information about the visual form of words, independent of semantics, what are the implications for studies of priming and implicit memory? In view of the finding that priming effects on such visual implicit tests as stem completion, fragment completion, and word identification are crucially dependent on encoding of visual surface feature information and are relatively independent of semantic encoding, I suggest that the visual word form system plays a significant role in these effects. More specifically, it is hypothesized that visual processing of a word (or a word pair) creates a representation of its particular visual features in the word form system. If we accept the idea that processing on standard completion and identification tests includes a major data-driven component—that is, performance is influenced heavily by the visual form of the test stimulus—then it seems reasonable to argue further that the visual word form system is engaged during implicit test performance.

If a specific representation has been created in the word form system during study, and the test stimulus matches critical visual features of that representation, then subjects will be better able to identify the word from a brief exposure or will be more likely to produce the word in response to a graphemic fragment. However, access to a word form representation does not entail retrieval of time and place information about when and where the word was encountered or the products of elaborative study processing. Accordingly, such access does not provide a basis for contextually specific explicit remembering. Because the word form system does not represent semantic/elaborative information, prior semantic study processing of a word should not lead to any more priming than nonsemantic study processing on completion, identification, and similar implicit tests, as is generally observed in the literature.

Although the foregoing ideas are in some respects similar to Morton's logogen notions, the critical difference is that by the present view, priming effects for the most part do not reflect the short-lived activation of some pre-existing, abstract representation. Instead, priming is held to be based largely on a specific, newly created visual representation in the word form system. Accordingly, the present view has no difficulty accommodating the fact that priming frequently exhibits a good deal of specificity and temporal persistence. But as stated earlier, specificity effects are not always observed, so it seems likely that under some circumstances activation of pre-existing representations plays a role in priming. It is possible that within the word form system, both activation of pre-existing, abstract representations and creation of novel, specific representations contribute to priming; the importance of each process may be determined by the nature of the target materials and the encoding operations required by a particular study task. Thus, when target words are presented for study in unusual formats or subjects are required by a study task to attend to the physical features of the words, priming may be based largely on novel word form representations; when words are not presented in unusual formats and study tasks do not require processing of a word's physical features, activation of pre-existing representations may play a more prominent role.

If implicit memory for words and other verbal materials depends crucially on creating and accessing representations in the word form system, what about explicit remembering of these items? Why, for example, are recall and recognition less sensitive to surface feature manipulations than are completion and identification performance? The answer, according to the present view, has to do with the manner in which retrieval is initiated. On implicit tests, subjects do not think back to the study episode intentionally; the task is to identify or complete a word, and their attention is focused on physical properties of the cue while performing this task. A simple way to carry out such tasks as word identification and completion is to rely on the output of the word form system. On an explicit test, in contrast, the task for subjects is to recollect what was studied during a particular episode. Attention is not focused exclusively on the physical properties of the cue; rather, the cue is used as a *guide* to aid reconstruction of the target item. The kinds of information that are typically useful for performing this task—elaborations concerning the target items, and contextual information about the time and place that the word was encountered—are not represented in the word form system. Thus, retrieval queries must be directed to a system or systems other than the word form system. The one that is most likely to be useful when performing explicit retrieval tasks is roughly equivalent to the episodic memory system discussed by Tulving (1972, 1983). (Note that the word form system and other components of PRS are "episodic" in the sense that they represent individual bits of information that are acquired during an episode. They do not, however, represent elaborative information that links an event to pre-existing knowledge nor do they represent time and place information; I use the term "episodic" only in reference to the system[s] that performs these functions). Even though the output of the word form system (or other subsystems of PRS) is not alone sufficient to support a "full-blown" re-experiencing of a recent episode, it might well support a rudimentary form of familiarity or perceptual fluency (cf., Jacoby & Dallas, 1981; Mandler, 1980): a recently established word form representation may pop to mind quickly, thereby providing a basis for a feeling of familiarity under some conditions. Accordingly, PRS likely contributes to recognition memory performance that is based on perceptual fluency or familiarity, rather than on contextual retrieval.

The foregoing ideas can accommodate data from normal subjects showing dissociable effects of semantic and surface feature manipulations on implicit and explicit tasks, specificity of priming effects within the visual modality, and long-lasting implicit memory effects, while at the same time providing a reasonable account of the amnesia data. With respect to the latter issue, the idea is that amnesic patients do not have impairments in the word form system, so they should show intact priming effects when an implicit task draws exclusively on this system. Therefore, the locus of amnesic patients' deficits would be either at the level of a damaged episodic system or an episodic system whose outputs are disconnected from awareness (see Schacter, 1989).

Additional support for the role of the word form system in priming is provided by a recent study of a letter-by-letter reader, PT. (Schacter, Rapscak, Rubens, Tharan & Laguna, in press). Letter-by-letter readers are generally unable to engage in "whole word" reading but can read if they are allowed to use a slow process of serially identifying successive letters of a word (e.g., Patterson & Kay, 1982; Warrington & Shallice, 1980). Once a word is identified, comprehension of word meaning is intact. In some cases of letter-by-letter reading, the deficit may be attributable to an impaired word form system (Warrington & Shallice, 1980), whereas in other cases the deficit appears to be attributable to an impairment in parallel (but not serial) transmission of letter information to an otherwise preserved word form system (Patterson & Kay, 1982). Neuropsychological assessment of patient PT provided strong evidence for preservation of the word form system (see Schacter *et al.*, in press, for details).

According to the present hypothesis that the word form system plays an important role in priming, PT ought to show robust priming effects on a task such as word identification, where studied and nonstudied words are exposed briefly and the patient attempts to read them. We investigated this hypothesis by allowing PT to study a list of target words by reading each word letter-by-letter; we then gave her a word identification test in which studied and nonstudied words were exposed briefly (i.e., 500 msec) and PT attempted to identify them. Despite the fact that the patient could only read correctly about 5–10% of nonstudied words on the basis of a 500-msec exposure, she showed a large priming effect in several experiments: PT identified from 30–45% of previously studied words from the 500-msec exposure. The priming effect was modality specific; no priming was observed following auditory study of words. Additional experiments showed that priming could not be attributed to explicit memory strategies, nor could it be attributed to letter-level processes (see Schacter *et al.*, in press). These results are both consistent with and provide additional empirical support for the idea that the word form system is critically involved in priming. In addition, this study illustrates the heuristic usefulness of the PRS framework: The present ideas led directly to testing a prediction about priming in a type of patient (a letter-by-letter reader) in which priming had not been studied previously.

It is important to point out at this juncture that the present argument does not hold that the word form system or PRS plays a key role in priming effects on *all* implicit memory tests. As noted above, implicit tests such as category instance production contain a large conceptually driven component. By the present view, priming effects on such tests reflect modifications of, or additions to, semantic knowledge and are based on systems other than PRS. The previously mentioned finding that some implicit memory effects are dependent on semantic study processing can be considered in light of this idea. One such effect is the phenomenon of implicit memory for newly acquired associations described by Graf and Schacter (1985, 1987; Schacter & Graf, 1986a, b, 1989). In these experiments, subjects studied unrelated word pairs (e.g., SHIP-CASTLE) and then performed a cued stem completion test in which they wrote down the first word that came to mind in response to a 3-letter stem that appeared next to a whole-word cue. Graf & Schacter found that subjects showed more priming when target word stems appeared with their study list cues (e.g., SHIP-CAS__) than when they appeared with other cues (e.g., MOTHER-CAS__), thereby indicating that a new association between the words influenced stem completion performance. Significantly, however, this associative effect was observed only when subjects had engaged in a study task that required processing of a meaningful link between the two target items (Graf & Schacter, 1985; Schacter & Graf, 1986a). In addition, this associative effect was significantly reduced by a study/test modality shift (Schacter & Graf, 1989). The modality specificity of this phenomenon fits well with the present view, but the fact that it depended on some type of semantic study processing may appear problematic: If the visual word form system—a nonsemantic system—is significantly involved in stem completion performance, why should semantic study processing be necessary to observe associative priming in the Graf and Schacter paradigm?

A possible resolution to this apparent paradox consists of the following notions: (a) the word form system drives completion performance on this task, so priming depends on a test cue matching a newly established representation of the visual features of the target pair and is therefore modality sensitive; (b) the cued stem completion task also induces some conceptually driven processing (more than the standard stem completion task), since the presence of the context word may lead subjects to try to retrieve semantically related items; and (c) the representation in the word form system does not itself contain semantic information, but can provide *access* to the system (be it episodic or semantic) that represents newly acquired semantic information about the pairs. Interactions between the word form system and the semantic system are crucial in reading (e.g., Schwartz *et al.*, 1980; Shallice & Saffran, 1986), and it seems likely that similar interactions could occur if an implicit memory task induced both data-driven and conceptually driven processing, as appears to be the case with the cued stem completion task. As long as we assume that the word form system can *interact* with other memory and cognitive systems, the Graf and Schacter data can be accommodated. Moreover, the notion that implicit memory for new associations entails an interaction between the word form system and either an episodic or semantic system may explain why associative effects in the Graf and Schacter paradigm are not shown by many amnesic patients (cf., Cermak *et al.*, 1988a, b; Schacter & Graf, 1986b; Shimamura & Squire, 1989): Damage to components of these systems may prevent the occurrence of associative effects.

Visual Object Agnosia and the Structural Description System

As mentioned earlier in the chapter, cognitive neuropsychological research has identified a number of subsystems of PRS in both the visual and auditory modalities. Accordingly, it is important to emphasize again that the present account does not maintain that implicit memory phenomena should be identified exclusively with the activities of the word form system or that this subsystem constitutes the sole basis of implicit memory. PRS represents just one type of system that can support implicit memory; for example, motor systems are likely involved in the ability of amnesic patients to learn motor skills without remembering the episode in which they acquired the skills (e.g., Milner, Corkin & Teuber, 1968). Moreover, the word form system is, in turn, just one of several subsystems of PRS that have been described. I will now consider another such subsystem, referred to as the *structural description system* (Humphreys, Riddoch & Quinlan, 1988; Riddoch, Humphreys, Coltheart & Funnell, 1988). This subsystem may support a rather different type of implicit memory effect from that attributable to the word form system.

The structural description system represents information concerning the form and structure of common visual objects. Importantly, however, this system does not represent associative or functional information about what an object means or how it is used; such information is represented in a semantic system with which the structural description system interacts. Evidence for a distinction between the representation of structural and semantic information about objects has been provided by studies of patients with various forms of *visual agnosia*—an inability to recognize familiar objects (for review and theoretical discussion, see Humphreys & Riddoch, 1987; Warrington, 1982). Consider, for example, a case described by Riddoch and Humphreys (1987a, b). Their patient was characterized by a modality-specific deficit in naming and recognizing objects from vision. Thus, when exposed visually to an object the patient could not name it, although he was reasonably good at providing the name from an auditory description. The patient also performed extremely poorly on various tasks that required access to semantic knowledge about an object from vision: he could not answer questions that probed stored functional knowledge (e.g., when shown a picture of an animal he could not accurately say whether it was kept as a pet) or associative knowledge (e.g., he could not say whether an animal was associated with a particular country); he also was extremely poor at matching pictures of objects to appropriate category names. His performance on all these semantic tasks improved considerably when they were carried out entirely in the auditory modality.

In contrast to his inability to gain access to semantic knowledge about objects from vision, the patient performed normally on tasks that tapped knowledge of object structure. Thus, for example, Riddoch and Humphreys tested the patient on an *object decision* task in which he had to decide whether a line drawing represented a real object or not. Some of the drawings depicted actual objects; others depicted nonobjects that were created by deleting critical features from real objects or adding incorrect features to them. The patient performed normally on this task, thereby indicating that he retained intact access to structural knowledge about objects (see Riddoch & Humphreys, 1987a, b, for other tasks revealing intact structural knowledge). On the basis of this and other cases (e.g., Sartori & Job, 1988; Warrington, 1975; Warrington & Taylor, 1978), several investigators (e.g., Humphreys & Riddoch, 1987; Riddoch & Humphreys, 1987; Riddoch *et al.*, 1988; Warrington, 1982; Warrington & Taylor, 1978) have argued that knowledge of the form and structure of objects is represented in a structurally based system that is distinct from, but interacts with, a semantic system that represents associative and functional knowledge about objects (for a different view, see Shallice, 1987). The structural description system, then, can be thought of as a subsystem of PRS that performs functions in the object domain that are similar to those performed by the word form system in the verbal domain.

Structural Descriptions and Implicit Memory for Visual Objects

Although the evidence from agnosic patients suggests the existence of a pre-semantic object representation system, the critical question for present purposes is whether this system can be implicated in implicit memory—that is, whether evidence exists that priming of visual objects depends on the structural description or some similar system. As argued elsewhere in an extensive review of studies on nonverbal priming (Schacter, Delaney & Merikle, in press), there have been few attempts to address this question. Moreover, many of the published studies are difficult to interpret because of failures to rule out the possibility that observed priming effects are attributable to explicit memory processes. In two recent lines of research, my colleagues and I have provided evidence that implicates the structural description system in priming of visual objects.

In one study, Schacter and Merikle (in preparation) examined whether nonsemantic study processing is sufficient to produce priming of familiar visual objects, just as nonsemantic study processing is sufficient to produce priming of familiar words in studies that were discussed earlier (e.g., Graf & Mandler, 1984; Jacoby & Dallas, 1981). Although studies of object priming have been reported, little attention has been paid to the question of whether such priming is a pre-semantic phenomenon (see Schacter *et al.*, in press, for discussion). To examine the issue, Schacter and

Merikle used a set of line drawings of familiar objects and perceptually degraded fragments of the same objects (the drawings and fragments were compiled by Merikle & Peterson [in preparation]). In the experiment, subjects initially viewed 14 line drawings (e.g., a whistle, a flower) for 5 sec per drawing. For half the drawings, subjects performed a *semantic* orienting task in which they generated functions for the depicted object; for the other half of the drawings, subjects performed a *structural* orienting task in which they counted the number of vertices in each object.

To assess priming, perceptual fragments of studied objects were presented together with an equal number of fragments that represented nonstudied objects. In previous studies using fragmented pictures, subjects have usually been asked to try to identify each object (e.g., Snodgrass, 1989; Warrington & Weiskrantz, 1968; Weldon & Roediger, 1987). However, such instructions allow and may even encourage subjects to use explicit memory strategies to aid object identification: that is, when subjects are asked to identify a fragment of an object, they will likely make use of any information that can aid task performance, including episodic information that is accessed through intentional, explicit retrieval strategies. Consistent with this idea,

TABLE 1. Object Completion and Object Recall Performance as a Function of Study Task[a]

Type of Test	Study Condition	
	Semantic	Structural
Completion	0.45	0.46
Recall	0.83	0.69

NOTE: On the completion test, subjects completed perceptual fragments of objects with the first object that came to mind; on the recall test, subjects were given the same fragments and were asked to remember the previously studied objects. For the completion test, baseline rate of completing fragments representing nonstudied objects with a target object was 0.22.

[a]From Schacter, D. L. & E. P. Merikle, in preparation.

Schacter *et al.* (in press) have noted that it has been difficult to obtain strong dissociations between priming and explicit memory with the traditional picture fragment completion paradigm.

To circumvent the foregoing problem, Schacter and Merikle altered the instructions for the fragment completion task so that subjects were told to respond to each perceptual fragment with *the first object that comes to mind* (see also Heindel, Salmon & Butters, in press). It was emphasized that there was no correct or incorrect answer on this task, and that any object that popped into mind in response to the fragment would be an acceptable response. To discourage further the use of explicit memory strategies, perceptual fragments were presented for 500 msec and subjects were instructed to respond as quickly as possible. A separate group of subjects was given an explicit memory test in which the same perceptual fragments were presented as cues, but subjects were instructed to think back to the study list and indicate which studied object they were reminded of by the test fragment.

The results of the experiment, depicted in TABLE 1, yielded three key outcomes: (1) significant priming was observed for studied objects relative to nonstudied objects; (2) the magnitude of priming was essentially the same in the semantic and structural encoding conditions; and (3) explicit memory performance was significantly higher in the semantic than in the structural encoding condition. The finding that the encoding manipulation affected recall but not completion performance indicates that the priming effect cannot be attributed to explicit memory; if priming were based on explicit retrieval, it, too, should have been affected by the encoding manipulation. The finding that priming was equivalent following the vertex-counting and function-generation tasks indicates that nonsemantic, structural study processing is sufficient to support implicit memory. These results are thus consistent with, and provide direct empirical support for, the hypothesis that priming of familiar visual objects depends on a presemantic perceptual system that can be dissociated from explicit memory.

In a second line of research on object priming, we have provided evidence in a series of studies that suggests that the structural description system is involved in priming of *novel* visual objects (Schacter, Cooper & Delaney, 1990a, b). In these experiments subjects were first exposed to a series of line drawings that depict unfamiliar and rather unusual 3-dimensional objects (see FIG. 1). Although none of the drawings represent actual objects, some of them depict *possible* objects whose surfaces and edges are connected in such a manner that they *could* exist as 3-dimensional entities in the real world; other drawings depict *impossible* objects that contain subtle structural violations that would prohibit them from actually existing in 3-dimensional form. Implicit memory for the objects was assessed with an object decision test in which subjects were given a 100-msec exposure to studied and nonstudied possible and impossible objects and were required to classify each object as possible or impossible. This task does not require explicit reference to, or conscious recollection of, the prior study episode. Thus, if object decision performance is higher for studied than for nonstudied items, there would be some evidence of implicit memory for the objects.

To perform the object decision test accurately, subjects must gain access to information about the global structure of each object: Classification of an object as "possible" or "impossible" requires a thorough analysis of the structural relations among components of the object. We believe that this task engages the structural description system. Therefore, object decision performance should be facilitated by prior study of an object if the study task involves encoding of global object structure; by the present view, such encoding will produce a new representation of the object in the structural description system. We examined this idea in our first experiment. One group of subjects performed an encoding task that required analysis of global object structure: They had to decide whether each object faced to the left or to the right. A second group was required to indicate whether each object had more horizontal or vertical lines; this task required encoding only local features of the object. Subjects were then given either an object decision test or a standard yes/no recognition test; subjects in the recognition group were in addition given an object decision test following the recognition test (for further methodological details, see Schacter *et al.*, 1990a). We expected that object decision performance would be facilitated by the left/right task, but not by the horizontal/vertical task.

The results generally conformed to this hypothesis. The data in TABLE 2 show the object decision data as a function of encoding task, studied versus nonstudied items,

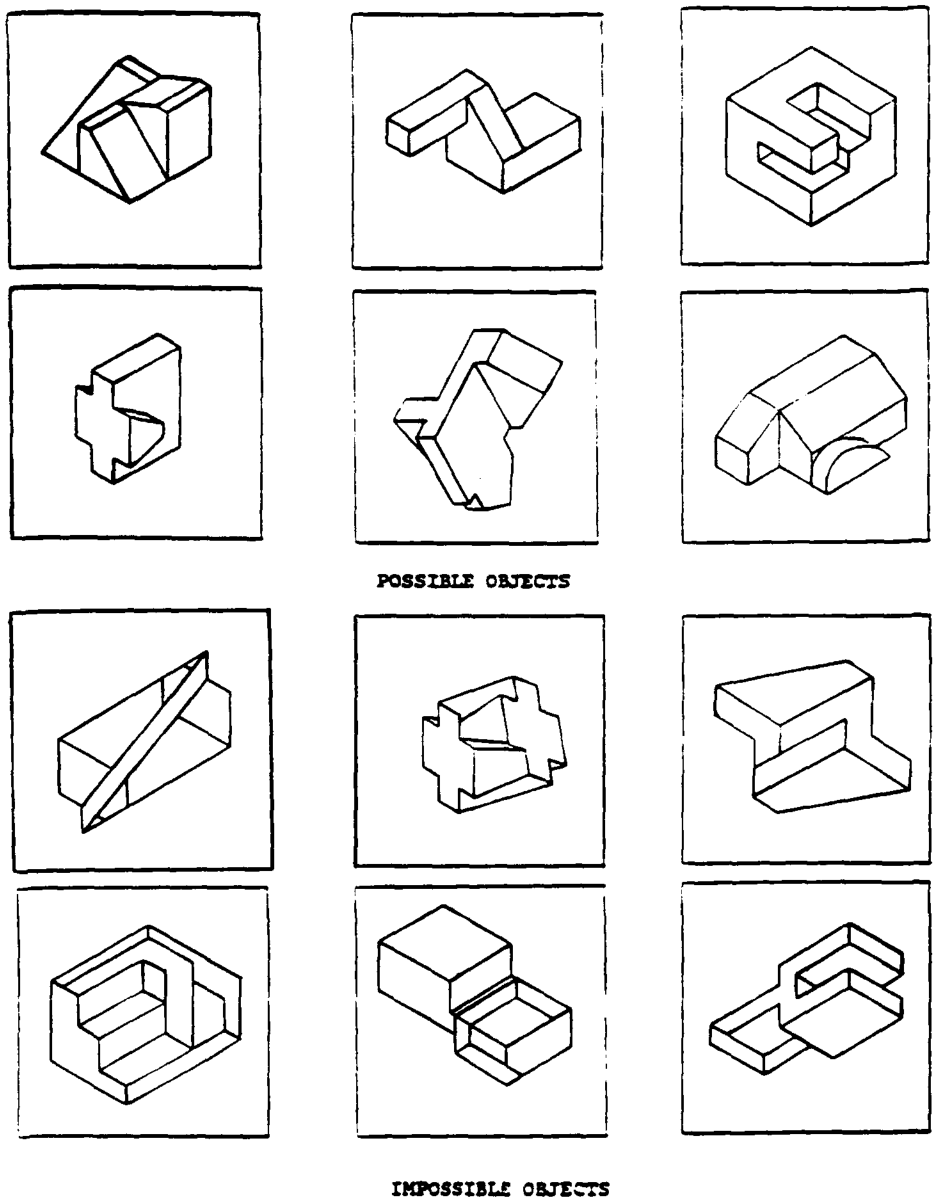

FIGURE 1. Sample objects taken from Schacter, Cooper & Delaney (1990a). The drawings in the upper rows depict *possible* objects that could exist in 3-dimensional form; the drawings in the lower rows depict *impossible* objects that contain structural violations that would prohibit them from actually existing in 3-dimensional form. See text for further explanation (copyright, American Psychological Association).

and test order (i.e., whether the object decision test was given alone [first test] or after recognition [second test]). Only the results for the possible objects are depicted; there was no evidence of priming for impossible objects in any of our experiments (see Schacter *et al.*, 1990a, for discussion). As indicated by TABLE 2, object decision performance was considerably more accurate for studied than nonstudied items following the left/right task, but there was weak and nonsignificant evidence of priming following the horizontal/vertical task; a significant interaction between type of study task and studied/nonstudied objects was observed. These data support the hypothesis that implicit memory for unfamiliar objects depends on access to a structural description of the target objects. In addition, performance on the object decision task was about the same in the first and second test conditions. This means that the appearance of studied and nonstudied items on the recognition test did not facilitate subsequent object decision performance—that is, deciding whether an object is old or new apparently does not entail the kind of structural encoding that is necessary to facilitate object decision performance. This finding suggests that a highly specific form of structural analysis is necessary in order to produce priming on an object decision test. The recognition test data revealed a nonsignificant difference between the left/right task (0.67 hit rate) and the horizontal/vertical task (0.61) although the difference in performance after these two tasks *was* significant on the object decision task. Moreover, a contingency analysis of the relation between object decision and recognition performance revealed stochastic independence between the two tests—the probability of responding correctly on the object decision task was uncorrelated with the probability of responding correctly on the recognition task. These results indicate that recognition and object decision performance rely on different types of underlying representations.

Further evidence indicating a dissociation between object decision and recognition performance, and also highlighting the presemantic nature of object decision priming, was provided by a second experiment in which we compared the left/right study task to an elaborative encoding condition. On the latter task, subjects were required to think of a real-world object that each drawing reminded them of most. We reasoned that this task would require subjects to achieve a meaningful interpretation of the object, generate their own elaborations, and relate the object to pre-existing knowledge of structures. These kinds of semantic encoding activities ought to enhance explicit *recognition* of the objects even more than does the left/right

TABLE 2. Object Decision Performance as a Function of Study Task, Test Order, and Item Type[a]

	Encoding Condition/Test Order					
	Left/Right			Horizontal/Vertical		
Item Type	First	Second	*M*	First	Second	*M*
Studied	0.81	0.81	0.81	0.72	0.63	0.67
Nonstudied	0.63	0.71	0.67	0.64	0.64	0.64
M	0.72	0.76		0.68	0.64	

NOTE: Each number in the table reflects the proportion of possible objects classified correctly on the object decision test.

[a] Adapted from Schacter, Cooper & Delaney (1990a).

TABLE 3. Object Decision and Recognition Performance as a Function of Study Task and Item Type[a]

	Encoding Condition			
	Object Decision Test		Recognition Test	
Item Type	Left/Right	Elaborative	Left/Right	Elaborative
Studied	0.78	0.76	0.69	0.88
Nonstudied	0.66	0.73	0.26	0.19

NOTE: For the object decision test, each number reflects the proportion of studied or nonstudied possible objects classified correctly. For the recognition test, the first row indicates the proportion of studied possible objects called "old" (hit rate) and the second row indicates the proportion of nonstudied possible objects called "old" (false alarm rate).

[a] Adapted from Schacter, Cooper & Delaney (1990a).

task. If priming of *object decision* performance is mediated by a structural description system that does not represent semantic information about objects, however, elaborative encoding should *not* lead to better object decision performance than does left/right encoding.

Relevant data are presented in TABLE 3, which displays the recognition results, as well as the object decision data collapsed across first and second tests (as in the first experiment, there were no differences between these conditions). These data reveal a clear dissociation between object decision and recognition performance: Whereas recognition memory was considerably higher following the elaborative encoding task than the left/right task, there was significantly less facilitation of object decision performance following elaborative than left/right encoding. In fact, although the overall level of performance in the elaborative condition was reasonably high (reflecting the high level of baseline performance even for nonstudied items), there was no difference between the studied and nonstudied objects. Thus, the same elaborative encoding manipulation that improved explicit memory for the objects eliminated implicit memory. This result is entirely consistent with, and provides support for, the notion that priming effects on the object decision task are mediated by a pre-semantic structural description system that does not handle semantic/associative information about objects.

CONCLUDING COMMENTS

The main argument of this chapter is that many implicit memory phenomena reflect the operation of subsystems of PRS that are dedicated to the processing of structural and form information in various input domains. As stated throughout the article, PRS is not held to be involved in *all* implicit memory phenomena; implicit tests that require conceptually driven processing (cf., Masson, 1989; Roediger *et al.*, 1989; Schacter, 1987) likely tap semantic and perhaps episodic forms of memory. The key point of the present proposal is that nonsemantic implicit tests such as fragment and stem completion, word identification, object decision, and others draw heavily on PRS. Two subsystems of PRS—word form and structural description—have been considered, but other perceptual subsystems have been postulated on neuropsychological grounds (e.g., Ellis & Young, 1988; Morton, 1979; Riddoch *et al.*, 1988). Though similar in some respects to Morton's logogen model, the present view holds that priming effects on many implicit tests are driven primarily by highly *specific, new* representations within a particular subsystem, rather than by the activation of *old, abstract* representations. It is possible to study the latter type of effect through the use of special masking procedures (e.g., Forster & Davis, 1984; Forster, Booker, Schacter & Davis, 1990), but activation of abstract nodes, units, or logogens cannot account for all the data reported in implicit memory experiments.

The ideas that have been put forward are here not so much inconsistent with existing notions as they are complementary to them. Although the present approach can be characterized as a multiple systems orientation, it incorporates the transfer-appropriate processing principle as a useful way of conceptualizing and describing implicit/explicit dissociations (cf., Hayman & Tulving, 1989). It also attempts to go beyond this, however, by drawing on relevant cognitive neuropsychological observations to specify more precisely the nature of the systems involved in implicit memory. And in agreement with processing views (cf., Roediger *et al.*, 1989; Witherspoon & Moscovitch, 1989), no claim is made that all implicit memory phenomena reflect the operation of a single memory system. In fact, the present view holds that implicit memory effects are linked to the activity of a variety of systems; precisely which system (or systems) contributes to performance depends crucially on the task that is used and the kind of knowledge that is tapped. Accordingly, the view adopted here (like processing approaches) allows for and even predicts the occurrence of dissociations among implicit tests, particularly between tests that tap PRS on the one hand and the semantic system on the other (cf., Blaxton, 1989). The present approach seeks to go beyond processing views, however, by placing some *structural constraints* on the processes involved in implicit memory. Similarly, most previous multiple system accounts of priming effects, though similar in spirit to this approach, have been somewhat vague regarding the exact nature and functions of the systems underlying implicit memory (e.g., Hayman & Tulving, 1989; Squire, 1987). By arguing that PRS plays a key role in many implicit memory tests, and specifying two candidate subsystems (word form and structural description), it is hoped that a sharper characterization of the systems involved in implicit memory can be achieved.

Finally, it is useful to consider more generally the manner in which the idea of "multiple memory systems" applies to the present formulation. Sherry and Schacter (1987) argued that the existence of independent processing modules that perform domain-specific computations need not be taken as *prima facie* evidence for the existence of multiple memory systems. For example, the modules could all output to a common memory system. Alternatively, even if each module had its own memory system, they could all operate according to similar rules. Sherry and Schacter suggested that it is only useful to talk about multiple memory systems when a case can be made that the systems operate according to different rules and perform distinct functions. One source of evidence for "different rules of operation" comes from empirical observations of dissociations produced by experimental variables and subject groups. However, this alone is not sufficient grounds for postulating multiple memory systems, because empirical dissociations *within* a system can be observed (e.g., Roediger, 1984). According to Sherry and Schacter (1987), it is also important to consider the *functions* that alleged systems perform. If the hypothesized systems perform different and mutually incompatible functions, then one has a stronger basis for postulating multiple memory systems.

With respect to the present account, it seems justifiable on both empirical and functional grounds to argue that the word form and structural description subsystems should be conceptualized as distinct from, but interacting with, episodic and other memory systems. Numerous dissociations reported in the literature, plus the object-priming studies described here, indicate that these systems operate quite differently from episodic memory. In addition, the functions performed by these systems—representation of form and structure within lexical (word form system) and object (structural description system) domains—are distinct from, and perhaps incompatible with, functions performed by the episodic system (i.e., representation of meaningful events composed of numerous types of information in particular spatiotemporal contexts). It is less clear, however, whether the word form and structural description systems are characterized by different rules of operations, which is why it seems most prudent to characterize them as subsystems of PRS. At the very least, the idea that these and other PRS subsystems play a key role in implicit memory seems worthy of further investigation. From a heuristic point of view, the idea suggests that careful attention to alexia, agnosia, and other neuropsychological syndromes that involve disruption of perceptual representation systems should pay rich dividends for implicit memory research (Schacter *et al.*, 1990a).

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DISCUSSION

J. FUSTER (*UCLA School of Medicine, Los Angeles, CA*): Did that patient with acquired dyslexia have an identifiable or documented lesion?

D. SCHACTER (*University of Arizona, Tucson, AZ*): Well, there have been three patients that I am familiar with in the literature so far. The original Schwartz, Marin, and Saffran patient had Alzheimer's disease, so there was obviously widespread pathology. There have not been precise lesion data provided for the two patients reported since then. One patient was reported by Funnel and one by Satori, Masterson, and Job. Both had left anterior strokes, so some general information is available. I can't give you a better answer to that question. The literature has not provided it yet.

FUSTER: Another question, a simple question: Why do you need to postulate dichotomies of the kind you do, when you might possibly be dealing with a gradual, graduated hierarchy, say, in cortex from the very concrete to the more general and categorical that might form a continuum, where the presentations would be stacked up from the most concrete, most data-driven to the most general, most categorical?

SCHACTER: Yes, there might well be a continuum in there, but I think in order to make these things sharp, at least in the beginning, one should begin with a dichotomy. If the dichotomy breaks down, well, so be it, but at least you can try to push the dichotomy and make it break down, so I wouldn't rule out that possibility.

A. SHIMAMURA (*University of California, Berkeley, CA*): I think that your framework is very nice. You have said explicitly what Larry [Squire] and I have felt implicitly. What is nice is that you have now pinned brain systems to some of these implicit memory systems, perhaps in neocortical areas, where the damage is not located in the areas where amnesic patients show damage. But in some sense, and correct me if I'm wrong, aren't you basically saying you can cross out "declarative" and put "semantic" there; cross out "nondeclarative" and put "nonsemantic" there; and underneath put the word form system, the structural description system, and. . . ?

SCHACTER: Yes, more or less. My view is consistent with your general point that in the implicit domain probably more than just one system exists. We're not talking about only two memory systems, one for explicit memory and one for implicit memory. What may make Roddy [Roediger] and others uncomfortable is that I'm talking about *several* memory systems. I think the saving grace, and the reason I am willing to entertain this possibility, is that there is the convergent and initially suggestive evidence from independent domains. If we simply postulate separate systems every time we have a dissociation, however, we are lost.

SHIMAMURA: Larry Squire, I, and our co-workers never really thought that all the abilities within the umbrella of procedural memory would be controlled by one brain system.

SCHACTER: No, I agree completely with Larry in that respect. I think his point has been for a number of years that within the procedural or implicit domain you are dealing with a lot of different systems. Here, I am trying to say let's get more specific about what the systems are and what functions they perform.

J. COHEN (*Carnegie-Mellon University, Pittsburgh, PA*): You used the priming effects on novel stimuli such as non-words as evidence against an activation-based approach or model. But I wonder why? It seems to me in that case it could just be priming of the orthographic phonological subunits, which would still be an activation-based explanation.

SCHACTER: Right. That is a good point, and I think it is something that comes up with any novel stimulus. That is, in what sense is it novel? There is perhaps, always a lower level at which the information is previously represented and you are just assembling it in a new way. However, at the level of words, the non-words obviously are novel—at the word level, but not at the letter level.

COHEN: I asked that question because I was wondering what a model or a mechanism underlying this implicit system would be, if it is not an activation-based model?

SCHACTER: Well, here we have another terminology issue. All of this could invoke activation in the very general sense that it is used in numerous models. But the activation explanation in this particular context refers specifically to the idea that you are not adding anything new to the system, you are just temporarily lighting up something that was already there, which dies down quickly. So it is not the activation concept that is at issue. I suppose it's the question of "old" versus "new" representations that is at issue. Is implicit memory based on the activation of old representations or the creation of new ones?

COHEN: It is still something old that you are lighting up, it's just at a lower level, that's all.

S. KEELE (*University of Oregon, Eugene, OR*): It seems to me that a failure we have had as psychologists is to define "semantics" in a way that we can make contact with neural systems. I don't know how to specify semantics. Where is it in the neural system, and what role does the hippocampus have in fixating a semantic memory? Do you have any ideas about what semantic memory might mean in a kind of pseudo-neurological sense?

SCHACTER: Well, I think the first thing I would say is that to me the difference between semantic and nonsemantic involves going beyond the structure of the stimulus as given; when you do that, you are passing into the semantic domain. Everything I have talked about as nonsemantic could be construed as dealing with the structure of the stimulus as given. As to the representation of semantics, again one can appeal to some of the data. Some of the Posner, Peterson, and Raichle work shows a more anterior focus of cerebral blood flow activation when you are doing semantic tasks. There is a massive literature showing that there seems to be a left hemisphere locus for these things; the literature goes back a long time. For example, I talked about the associative agnosias. You generally don't get that without some sort of a left hemisphere lesion. So, one can hand-wave a little bit about that, but as for the hippocampus and semantics, that becomes a very difficult issue.

L. NADEL (*University of Arizona, Tucson, AZ*): Let me add something to that. The word "semantic" is another one of those unfortunate words that has been used by psychologists in a way that is somewhat similar to, but actually quite different from, the way in which it has been used in psycholinguistics. The notion of "semantics" that arises in the distinction between syntax and semantics is very different from the notion of semantics entailed by the distinction between episodic and semantic. Consequently, there has been confusion about this notion of semantic with respect to the sense in which we are using it. Mostly we are talking about it in a way that is quite different from the way that language people talk about it. That has led to confusion.

SCHACTER: In the object domain I think you can make somewhat of a sensible distinction if you talk about a semantic domain composed of functional, associative, and perhaps contextual properties of an object. These go beyond the physical form and structure of an object; the presemantic system that I have discussed is restricted to that physical form.

J. FAGAN (*Case Western Reserve University, Cleveland, OH*): What is the matter with the word "meaning"?

SCHACTER: Nothing. Nothing at all.

FAGAN: Is that what you mean by "semantic"? Does "semantic" mean "something that has meaning"?

SCHACTER: Yes, it means that in a certain sense.

J. WERKER (*University of British Columbia, Vancouver, B.C.*): I can't help but be reminded of some more ancients in developmental psychology. Bruner and Werner come to mind, with their sensorimotor, perceptual, and conceptual sorts of representations. I like the distinction between something like "perceptual" and something like a "semantic representational system." I think that distinction might be very useful. I like your use of the word "meaning" rather than "semantic," because I always worry that what we are left with is that the only thing that qualifies as semantic memory is something we can talk about. I think of the split brain studies. Would it be that anything that is in the right hemisphere in a split brain patient can't possibly qualify as semantic memory?

SCHACTER: No, I don't think that, in principle, would be true. No, I think you can express semantic or meaningful knowledge without language, using other response systems.

WERKER: Right.

NADEL: With respect to this whole idea, I would like to add a historical note. There's a chapter called "Limited Amnesias" in a book called *Amnesia*: agnosias, apraxias, and a variety of such syndromes are discussed as limited forms of amnesia.[b] That was the first statement that I have seen of the idea that one can think about these early processing systems as modular, representational, or memory systems. Psychologists at that time were restricting the use of the term "memory" to what Miller called "grade A certified learning," which is now called episodic memory. We are now using the word "memory" in a much broader sense, to include anything that reflects some impact from prior experience. So, the field has moved, but these ideas have been around for some time. They just haven't been talked about in the same way.

SCHACTER: Certain aspects of the ideas, yes.

R. CASE (*Stanford University, Stanford, CA*): At the beginning of your talk you said a problem with Roddy [Roediger's] transfer-appropriate processing view was that it had trouble dealing with certain kinds of things that amnesics can do, which you might expect they couldn't do, which are of a conceptual nature. I have forgotten your example, but could you come back to it and show how your view *does* allow you to account for that?

SCHACTER: Well, for example, category instance production, or some work Art [Shimamura] has done with priming of semantic associates. Art can describe the paradigm better than I.

SHIMAMURA: Well, you give a paired associate like "table" and "chair." Later on you give the word, "table," and ask subjects to free associate to it.

SCHACTER: Or the one where you don't present the actual associate. These are what would be thought of as conceptually driven tasks. Now, what I would say is that is not in the domain of the perceptual systems I have discussed. That is, using implicit tests to tap into a semantic system we find that, at least with respect to old knowledge in the semantic system, amnesics are OK; they show substantial priming of pre-existing semantic knowledge. It's another issue as to whether amnesics can add anything new to the semantic system. Harking back to the discussion we had before about the kind of mixed findings that have been found with the priming of novel paired associates, which involve some semantic processing. From my point of view, one might think of that as now getting out of the domain of these perceptual systems,

[b] LISMAN, W. A. 1966. Limited amnesias. *In* C. W. M. Whitty & O. L. Zangwill, Eds. Amnesia. Butterworths. London.

into perhaps some cross-talk between perceptual and semantic systems, because these novel associate priming effects are both modality-specific and semantically dependent. Perhaps when you get into the cross-talk of these systems you don't get the purely preserved effect in amnesics that you do when you stay safely within one of these systems. That is just a speculation.

H. L. ROEDIGER (*Rice University, Houston, TX*): I take it from your presentation that the two new systems you have proposed would account for the data that I have collected, but they don't really solve the same problem I was facing. That is, the story would have been quite neat if amnesics only showed preserved priming on perceptual (or data-driven) implicit tests, but they don't. They are preserved on semantic (or conceptually driven) tests, too. Your perceptual representation systems handle perceptual priming, but you still have to face conceptual priming. So we must need another priming system for conceptual priming.

SCHACTER: Well, I think then you get squarely into the semantic–episodic kind of issue, and if you allow amnesics to have a reasonably well-preserved semantic knowledge base—it's then a question of whether they can add anything new to it—but then some of these priming effects could be working off of that.

ROEDIGER: How many systems do you think we will wind up with with this logic? When I read the neuropsychology literature it seems like every time you get a specific knowledge deficit in a patient a new neural system is proposed. If some brain lesion produces an inability to identify yellow Volkswagens but not green Volkswagens, then right away someone proposes that we have a system for green Volkswagens and a different system for yellow ones.

SCHACTER: Yes, obviously one wants to stay away from that. I think the appeal that you and others have made to converging evidence is the best way. I think with the perceptual representation system idea, we can make a reasonably coherent story by bringing together three separate domains: cognitive and neuropsychological studies of implicit memory, neuropsychological studies of reading and object-processing deficits, and neuroimaging studies.

ROEDIGER: Right. With converging operations the systems business makes good sense. I agree.

SCHACTER: With the structural description hypothesis, you can bring together the object agnosia data and the priming results. I think this makes some rather nice predictions about what should happen in PET studies that we will hopefully actually be able to look at. So, I would say we have to rely on the converging evidence and some sensible, principled idea about the function of systems, so we don't have a million of them. I would say that if you took a fast reading of the current cognitive neuropsychological literature, with the way a number of people are thinking about it, you would find evidence for at least four of these perceptual representation systems. I have talked about two of them (the word form system and the structural description system). Others have found some preliminary evidence in the auditory domain for a couple of others—again, one would want to see more evidence of different kinds before accepting these systems, but at least the hypothesis suggesting these other systems is worth investigating. It is probably best to refer to these four as subsystems of a more general perceptual representation system, because they may all function in fundamentally similar ways, albeit with respect to different types of perceptual information.

Atch 2

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Implicit memory for visual objects and the structural description system

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Several experiments are described in which priming or implicit memory for visual objects was investigated. In one set of studies, subjects were shown line drawings of unfamiliar objects that were either structurally possible or structurally impossible. Implicit memory was assessed with a possible/impossible object-decision task, and explicit memory was assessed with a recognition task. The results revealed significant priming for possible objects following study tasks that required encoding of three-dimensional object structure; semantic/elaborative study processing enhanced explicit but not implicit memory. No priming of impossible objects was found. An experiment using familiar objects also revealed that priming, but not explicit memory, was independent of semantic/elaborative study processing. It is suggested that priming of visual objects depends on a presemantic system that is dedicated to the representation of object form and structure and can function independently of episodic memory.

Research on priming and implicit memory has focused heavily on verbal materials such as words, paired associates, and the like. There has been a good deal less research on implicit memory for nonverbal materials, and with the exception of work by several investigators (e.g., Bentin & Moscovitch, 1988; Gabrieli, Keane, Milberg, & Corkin, in press; Kroll & Potter, 1984; Musen & Treisman, 1990), this research has focused exclusively on priming of pictures of familiar objects (for a review, see Schacter, Delaney, & Merikle, in press). In this paper, we describe a series of recent studies in which we have examined priming for both novel and familiar visual objects. To preview our main findings, we documented priming of both types of objects, showed that such priming depends on processing of structural but not semantic information, and dissociated implicit and explicit memory for target objects. We will argue that priming of visual objects depends on what we and others have referred to as the *structural description system* (Riddoch & Humphreys, 1987; Schacter, in press; Schacter, Cooper, & Delaney, 1990)—a presemantic system that is dedicated to the representation of the form and structure, but not the functions or other associative properties, of visual objects.

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Object-Decision Priming: Initial Studies

The first series of experiments to be considered was directed to the question of whether implicit memory could be observed for novel three-dimensional objects that have no preexisting representation in memory. In an initial experiment and several others that will be described, subjects studied 20 line drawings that represented unfamiliar and rather unusual three-dimensional constructions such as those displayed in Figure 1. Two encoding conditions were used. One group of subjects was induced to encode information about the global structure of each object by deciding whether the object faced primarily to the left or to the right. A second group of subjects was induced to encode information about the local features of each object by deciding whether it had more horizontal or vertical lines.

After completing these encoding tasks, half of the subjects in each group were given an explicit memory test—a standard yes/no recognition test in which they were shown studied and nonstudied drawings and indicated whether or not they remembered seeing them previously. The other half of the subjects were given an object-decision test. Although the subjects were not informed of it at the time of encoding, half of the line drawings that they studied were structurally *possible* objects—their surfaces and edges were connected in such a way that they could potentially exist in three-dimensional space. The other half were structurally *impossible* objects—they contained surface and edge violations that would prohibit them from actually existing in the three-dimensional world. We gave the

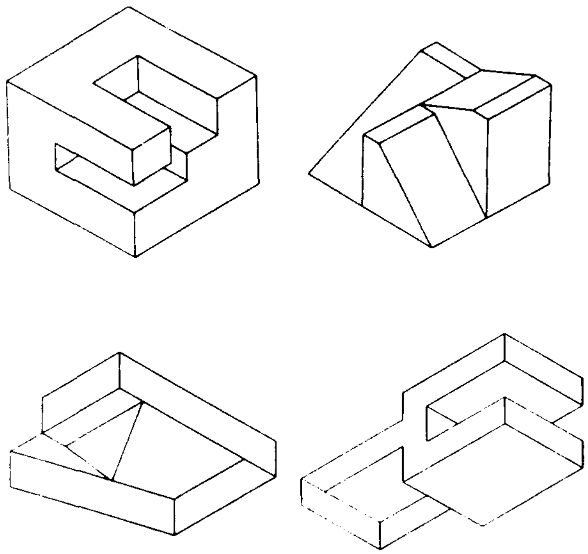

Figure 1. Examples of novel objects used in the experiments by Schacter, Cooper, and Delaney (1990). The two objects in the upper row are structurally *possible*; the two objects in the lower row are structurally *impossible*. See text for further explanation.

subjects 100-msec exposures to drawings of studied and nonstudied possible and impossible objects; their task was to decide whether each object was possible or impossible. The object-decision task can be thought of as an implicit memory test in the sense that it does not make explicit reference to, or require conscious recollection of, any specific previous encounter with a presented object. If, therefore, subjects are more accurate in making object decisions about studied than about nonstudied objects, there would be some evidence of implicit memory for these unfamiliar, three-dimensional objects. More specifically, we reasoned that performing the object-decision test requires analysis of the global structure of the object; subjects must gain access to information about global structural relations in order to decide whether an object is possible or impossible. Consistent with such notions as transfer-appropriate processing (e.g., Roediger, Weldon, & Challis, 1989), it follows that prior encoding of information about global object structure—but not local object features—should produce priming or implicit memory on a subsequent object-decision task.

The results of our first experiment were consistent with this hypothesis. Consider first the results for the structurally possible objects. We examined object-decision performance as a function of the left/right or horizontal/vertical encoding task and as a function of whether or not an item had been studied. In addition, the group of subjects who were given the recognition test were also given an object-decision test after it. Thus, we could examine object-decision performance as a function of whether it was given as the first or the second test.

The data presented in Table 1 are collapsed across the two object-decision tests, because performance did not differ as a function of whether object decision was the first or second test (see Schacter, Cooper, & Delaney, 1990). Table 1 indicates that object-decision performance was significantly more accurate for studied than for nonstudied drawings following the left/right study task. However, there was no significant difference between studied and nonstudied objects following the horizontal/vertical study task. Thus, we found that implicit memory for unfamiliar objects depends on the encoding of and access to a global, three-dimensional structural description of an object. In addition, the fact that the appearance of studied and nonstudied objects on the recognition test did not facilitate subsequent object-decision performance suggests that deciding whether an object is old or new, at least under these test conditions, does not involve the sort of structural encoding that is needed to produce priming on an object-decision test. Table 1 also indicates that the structurally impossible objects showed no priming under any experimental condition: object-decision performance for studied and nonstudied impossible objects was virtually identical.

Whereas priming of novel, structurally possible objects was observed only following global structural encoding, the recognition data indicated that explicit memory did not differ significantly following the left/right and horizontal/vertical study tasks (Schacter, Cooper, & Delaney, 1990). In addition, recognition of impossible objects, although lower than recognition for possible objects, was reasonably good, in contrast to the absence of priming for impossible objects. Finally, a contingency analysis of the relation between recognition and priming revealed stochastic independence between the two tasks.

Further evidence for implicit/explicit dissociation was provided by a second experiment, in which one group of subjects engaged in an elaborative encoding task that required them to generate a real-world object that each drawing reminded them of most (Schacter, Cooper, & Delaney, 1990, Experiment 2). We hypothesized that such a task would require the subjects to achieve a meaningful interpretation of the object by relating it to preexisting semantic knowledge. On the basis of many previous demonstrations that explicit memory is enhanced by semantic elaboration, we reasoned that this elaborative study task should enhance recognition performance relative to the left/right encoding task used in the first ex-

Table 1
Object-Decision Performance as a Function of Encoding Task

Item Type	Encoding Task: Left/Right	Encoding Task: Horizontal/Vertical
Possible Objects		
Studied	.81	.67
Nonstudied	.67	.64
Impossible Objects		
Studied	.67	.60
Nonstudied	.67	.63

Note—Data are adapted from Schacter, Cooper, and Delaney (1990).

Table 2
Object-Decision and Recognition Performance as a Function of Encoding Task

	Type of Test/Encoding Task			
	Object Decision		Recognition	
Item Type	Left/Right	Elaborative	Left/Right	Elaborative
Studied	.78	.76	.69	.88
Nonstudied	.66	.73	.21	.19

Note—Data are presented for structurally possible objects only. For object decision, the proportion of correct responses to studied and nonstudied objects is shown; for recognition, the proportion of "yes" responses to studied objects (hits) and "yes" responses to nonstudied objects (false alarms) is shown. Data are adapted from Schacter, Cooper, and Delaney (1990).

periment. However, since the elaborative task does not involve specific *structural* encoding of the objects, it should not lead to more accurate object-decision performance than did the left/right task.

The results were consistent with this expectation, and in fact revealed a rather dramatic dissociation between recognition and object-decision performance (Table 2). We will consider only the structurally possible objects, since the impossible objects once again showed no priming. On the recognition test, elaborative encoding led to much higher levels of explicit memory than did left/right encoding. A contrasting pattern of results was observed on the object-decision task: no priming was observed following the elaborative task, whereas significant priming was observed following the left/right task, in replication of Experiment 1. This dissociation is impressive because there have been few studies in which an experimental manipulation that improves explicit memory also impairs implicit memory. However, the fact that we observed no priming in the elaborative condition was rather surprising. In a follow-up experiment, we were able to show that this lack of priming was attributable to the fact that subjects frequently generated two-dimensional elaborations of the target objects (e.g., indicating that a side of the object reminded them of a letter, a cross, etc.). When we asked them to generate three-dimensional elaborations, significant priming was observed, although it was no greater than that observed in the left/right condition (Schacter, Cooper, & Delaney, 1990, Experiment 3).

In each of the foregoing experiments, object-decision performance was assessed after a retention interval of several minutes. To determine whether the priming effect observed under these conditions persists across longer delays, we have more recently assessed object-decision and recognition performance after retention intervals of 1 or 24 h. All 72 subjects who participated in the experiment performed the left/right encoding task described in the previous experiments, and the same set of objects described by Schacter, Cooper, and Delaney (1990) was used. Half of the subjects were tested after a 1-h delay, and half were tested after a 24-h delay; at each delay, 18 subjects were given an object-decision task alone and 18 were given the object-decision task following a yes/no recognition test.

Object-decision data for the two delays are presented in Table 3. Consider first the data for the structurally possible objects. At the 1-h delay, significant priming of possible objects was observed, and the difference between studied and nonstudied items was about the same whether the object-decision test was given alone or following a recognition test. Although there was a trend for overall higher performance when the object-decision test was given following the recognition test, statistical analysis revealed only a main effect of priming (i.e., studied vs. nonstudied objects; $p < .001$); there was a nonsignificant main effect of test order and no interaction between test order and priming. At the 24-h delay, there was some evidence of priming when the object-decision test was given alone, but there was no difference between the two when the object-decision test was given second (Table 3). This latter finding may be attributable to a test-priming effect for nonstudied objects. However, statistical analysis failed to show significant main effects of priming or test order and also showed a nonsignificant interaction between these two variables. Finally, no priming of impossible objects was found at either delay. On the recognition test, performance declined from 1 to 24 h for both possible and impossible objects: corrected recognition (hits − false alarms) scores for possible objects were .56 at the 1-h delay and .38 at the 24-h delay; the corresponding proportions for impossible objects were .46 and .24.

The foregoing data indicate that priming effects for structurally possible objects are robust at a 1-h delay; the magnitude of priming in this condition is comparable to that observed after a delay of several minutes. Although there was a trend for priming at the 24-h delay when the object-decision test was given alone, these results are equivocal at best and require further empirical investigation.

Is There Priming with Structurally Impossible Objects?

As noted above, an intriguing finding from the initial set of experiments concerns the failure to observe prim-

Table 3
Object-Decision Performance as a Function of Retention Interval and Test Order

	Retention Interval/Test Order					
	1 Hour			24 Hours		
Item Type	First	Second	*M*	First	Second	*M*
	Possible Objects					
Studied	.80	.87	.84	.76	.77	.77
Nonstudied	.68	.77	.73	.68	.76	.72
M	.74	.82		.72	.77	
	Impossible Objects					
Studied	.60	.70	.65	.71	.64	.68
Nonstudied	.62	.66	.64	.74	.62	.68
M	.61	.68		.73	.63	.68

Note—Test order refers to whether object decision was the first test given at the end of the retention interval, or the second test given, after a yes/no recognition test.

ing of impossible objects despite reasonably good explicit memory for these objects. Schacter, Cooper, and Delaney (1990) speculated that this failure may reflect a limitation of the structural description system's computational capacities: it may be difficult to form a global representation of the structure of an impossible object. However, other interpretations of the phenomenon are possible. For example, in order to select the set of possible and impossible objects used in the foregoing experiments, we initially presented the objects to a separate group of subjects for an *unlimited* amount of time and asked for a possible/impossible judgment. These subjects classified 97% of the possible objects correctly under these unlimited viewing conditions, but they classified only 87% of the impossible objects correctly. Failure to observe priming of impossible objects might thus be partially attributable to the fact that there was less agreement about the impossible objects than about the possible objects. In addition, our instructions on the object-decision test emphasized detection of possible objects; the subjects were instructed to push one response key if an object "could be a possible object" and another if it "could not be a possible object." An impossible response was thus effectively a negative response, which might have worked against observing priming of the impossible objects. Finally, explicit memory for impossible objects in our initial experiments was consistently lower than explicit memory for possible objects. Thus, failure to observe priming of impossible objects may be attributable to a generally "weak" memory representation.

To evaluate these issues, and to explore further the nature of priming for possible objects, we have recently undertaken a series of experiments containing several procedural changes (Schacter, Cooper, Delaney, Peterson, & Tharan, 1990). First, we calibrated a new set of target objects in which there was 99% agreement for both the possible and the impossible objects. We also altered the task instructions so that an "impossible" response was no longer a negative response, and added several more examples of impossible objects to the instructional phase of the test to ensure that the subjects fully understood what made an object impossible.

We then examined priming following the left/right structural encoding task used in the previous experiments under two conditions of repetition: the study list of 20 possible and impossible objects was presented either once or four times, with the subjects thus making four left/right judgments for each object in the latter condition. Inclusion of the four-repetition condition served two purposes. First, if priming of impossible objects is not observed even after four left/right judgments, when explicit memory is likely to be quite good, then it would be difficult to argue that a lack of priming for impossible objects is simply attributable to a weak memory representation. Second, the repetition manipulation also allowed us to determine whether the magnitude of the priming effect for possible objects can be increased. The number of repetitions was a between-subjects factor; the design of the experiment was otherwise identical to the previous ones.

Consider first the results from the recognition test. Not surprisingly, recognition memory (as assessed by a hits − false alarms measure) was significantly ($p < .05$) higher following four exposures than following one exposure for both possible objects (.70 vs. .41) and impossible objects (.62 vs. .33). A rather different pattern of results was observed for the object-decision data for possible objects. In the one-exposure condition, a priming effect similar to that observed in the previous experiments was found: object-decision accuracy was higher for studied (.74) than for nonstudied (.62) possible objects. In the four-exposure condition, object-decision performance showed a virtually identical pattern (.71 for studied objects and .58 for nonstudied objects). Statistical analysis revealed a main effect of priming ($p < .01$) and a nonsignificant interaction between priming and number of repetitions. Thus, repetition had a large effect on recognition performance and no effect on the magnitude of priming, thereby providing yet another dissociation between implicit and explicit memory for novel objects.

Turning to the data on the impossible objects, object-decision performance was indistinguishable for studied and nonstudied objects following both one study-list exposure (.67 vs. .67) and four study-list exposures (.66 vs. .65). Indeed, a lack of priming for impossible objects in the four-exposure condition was observed even though recognition of impossible objects in this condition was a good deal higher than recognition of possible objects following a single exposure, where significant priming was observed. Thus, the absence of priming for impossible objects cannot be ascribed to some sort of generally weak memory representation of these objects. These results also provide evidence against the idea that a failure to observe priming of impossible objects is attributable to low agreement about the impossible objects or to test instructions that make the "impossible" response a negative response.

The foregoing results suggest that it may indeed be impossible to observe priming of impossible objects, but further research is needed before such a conclusion is warranted. For example, in the studies discussed thus far, no attempt was made to equate the size of possible and impossible objects. In recent pilot work we have investigated priming with size-equated objects. Although we do not yet know whether this experiment will show priming for impossible objects, it underscores the need for caution in interpreting the data on impossible objects.

Priming of Familiar Visual Objects

Our studies with the object-decision task indicate that priming of novel objects is dependent on encoding structural, but not semantic, information about target items. Similar conclusions have been suggested by a recent experiment on priming of familiar visual objects (Schacter & Merikle, 1990). A sizable body of literature exists concerning priming of familiar objects, but little attention has been paid to the roles of structural and semantic encoding processes (see Schacter et al., in press, for a discussion). To investigate this issue, we used a set of materials that was compiled from a variety of sources by E. P. Merikle and M. A. Peterson, which consisted of line drawings of familiar objects and perceptually degraded fragments of these objects. Merikle and Peterson selected fragments in which minima of curvature were preserved, thereby providing useful perceptual information about each object.

In the Schacter and Merikle (1990) experiment, subjects were initially exposed to a series of line drawings of each object for 5 sec; they performed a semantic orienting task for half of the drawings and a structural orienting task for the other half. In the semantic orienting task, the subjects generated functions for each object; in the structural task, the subjects counted the number of vertices in each object. To assess priming, perceptual fragments of studied objects were presented together with an equal number of fragments of nonstudied objects. In previous studies of picture fragment completion, subjects have generally been asked to identify each object (e.g., Snodgrass, 1989; Warrington & Weiskrantz, 1968; Weldon & Roediger, 1987). As Schacter et al. (in press) have pointed out, however, such instructions allow and may even encourage subjects to use explicit memory strategies to aid object identification, as indicated by the fact that strong dissociations between priming and explicit memory have been difficult to obtain using the traditional picture fragment-completion paradigm. To circumvent this problem, Schacter and Merikle modified the fragment-completion instructions so that the subjects were told to respond to each fragment with the first object that came to mind. The subjects were further instructed that there was no right or wrong response on this task, and that any object would do as a completion response (see Butters, Heindel, & Salmon, 1990, for a similar procedure). To further discourage the use of explicit strategies, fragments were presented for 500 msec and the subjects were instructed to respond as quickly as possible. A separate group of subjects was given an explicit memory test in which the same fragments were presented as cues, but these subjects were instructed to think back to the study list and indicate which studied object was represented by the test fragment.

The results revealed significant priming ($p < .01$) on the *fragment-completion* task and, more importantly, almost identical levels of priming following the semantic and structural study tasks: baseline probability of responding with the correct object for nonstudied items was .22, compared to .45 for objects that had been studied in the semantic task and .46 for objects that had been studied in the structural task. In contrast, explicit memory was significantly ($p < .05$) higher in the semantic condition (.83) than in the structural condition (.69). The fact that performance was higher in the semantic than in the structural condition with recall instructions, but not with completion instructions, indicates that the priming effect was not based on explicit memory. The fact that priming was just as large following the vertex-counting task as following the function-generation task indicates that nonsemantic, structural processing is sufficient to produce robust priming of familiar visual objects.

Priming of Visual Objects: Theoretical Implications

Our experiments have delineated two features of priming, which were observed with novel objects on the object-decision task and familiar objects on the fragment-completion task, that are of special theoretical relevance. First, the phenomenon is presemantic, in the sense that priming does not require any semantic or elaborative processing of target objects. Second, encoding of information about object structure appears to be a sufficient and perhaps necessary condition for priming. In these respects, object priming is similar to more extensively studied word-priming effects on data-driven implicit tests such as word identification and word completion, where priming is typically independent of semantic study processing and depends critically on encoding of appropriate perceptual and structural information about words (Roediger et al., 1989; Schacter, in press).

We have found it useful to conceptualize these kinds of presemantic, perceptually dependent priming effects in the context of neuropsychological studies concerning disorders of reading and object processing. This line of research has provided strong evidence for the existence of presemantic systems that are dedicated to the representation and retrieval of information about the form and structure, but not the meaning, of words and objects. Specifically, we have argued that a presemantic perceptual representation system (PRS), composed of a number of related subsystems, plays a major role in priming on data-driven implicit tests (see Schacter, in press; Schacter et al., 1990; Tulving & Schacter, 1990). In the verbal domain, various kinds of neuropsychological and neuroimaging evidence have provided converging support for the existence of a visual word-form system (e.g., Peterson, Fox, Posner, & Raichle, 1988; Schwartz, Marin, & Saffran, 1980). We have argued that this subsystem of PRS is critically involved in word-priming effects on such implicit tests as word identification and completion (Schacter, in press; Schacter, Rapscak, Rubens, Tharan, & Laguna, 1990).

More directly relevant to the present experiments is the neuropsychological research by Warrington (1975, 1982) and Riddoch and Humphreys (1987) concerning agnosic patients with object-recognition disorders. These investigators have studied patients who are seriously impaired in gaining access to semantic or functional information about objects. Such patients cannot name common objects, are unable to answer questions about what such objects are used for, and fail to demonstrate knowledge of where familiar objects are typically found. Yet the same patients perform reasonably well on tests that require processing of object structure. These kinds of dissociations have led to the postulation of a presemantic structural description system for objects (Riddoch & Humphreys, 1987; Warrington, 1982), which we view as a subsystem of PRS. We believe that object priming in our experiments is driven largely by this system—that is, initial study of an object creates a structural description of it, which is then accessed implicitly during performance of an object-decision or object-completion test, thereby producing priming. This priming effect appears to be independent of subjects' explicit memory for the objects, which we believe is handled by an episodic memory system.

We should stress that we have opted for a multiple-systems interpretation of our data because of the existence of converging evidence from independent lines of investigation: the neuropsychological research described above has provided evidence concerning the nature of the structural description system, and our studies indicate that priming of both novel and familiar objects is a presemantic phenomenon that can be experimentally dissociated from explicit memory. Although we think that our position is complementary to, rather than in conflict with, the processing views of implicit memory advocated by such investigators as Roediger et al. (1989), Moscovitch, Winocur, and McLachlan (1986), Jacoby (1983), and Masson (1989), we wish to emphasize the usefulness of a systems approach in organizing and integrating diverse observations concerning the nature of implicit memory.

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Implicit Memory for Possible and Impossible Objects: Constraints on the Construction of Structural Descriptions

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Four experiments examined implicit memory or priming effects on an object decision task in which subjects decided whether structurally possible or impossible novel objects could exist in three-dimensional form. Results revealed equivalent levels of priming for possible objects after 1 vs. 4 5-s exposures to the same structural encoding task (Experiment 1) and when objects were studied with a single structural encoding task or 2 different structural encoding tasks (Experiment 3). Explicit memory, by contrast, was greatly affected by both manipulations. However, priming of possible objects was not observed when Ss were given only a single 1-s exposure to perform a structural encoding task (Experiment 2). No evidence for priming of impossible objects was observed in any of the 4 experiments. The data suggest that object decision priming depends on a presemantic structural description system that is distinct from episodic memory.

Implicit memory refers to unintentional retrieval of previously acquired information on tests that do not require conscious or explicit recollection of specific previous experiences (Graf & Schacter, 1985; Schacter, 1987). Perhaps the most extensively investigated type of implicit memory is known as *direct priming*: facilitated performance on an implicit memory test following exposure to a specific stimulus (e.g., Cofer, 1967; Tulving & Schacter, 1990). Although there is considerable evidence that priming and explicit memory can be dissociated by various experimental manipulations and subject factors (Richardson-Kavehn & Bjork, 1988; Schacter, 1987; Shimamura, 1986), most of this evidence is based on studies that have used words and other verbal materials. There has been considerably less research concerning implicit memory for nonverbal information, and much of this work has examined priming on tasks that include a significant verbal component, such as naming or identifying pictures of common objects (cf. Durso & Johnson, 1979; Jacoby, Baker, & Brooks, 1989; Mitchell & Brown, 1988; Warren & Morton, 1982; Warrington & Weiskrantz, 1968; Weldon & Roediger, 1987; for review and discussion, see Schacter, Delaney, & Merikle, 1990).

As Schacter et al. (1990) pointed out, research on priming of nonverbal information is important for a number of reasons: (a) It is necessary to provide a broad empirical picture of the nature and characteristics of priming, (b) it will help to ensure that theorizing about implicit memory is not overly constrained by idiosyncratic properties of verbal materials, and (c) it can suggest links between the study of memory and the study of perception. In addition, because memory for nonverbal information must have developed earlier in phylogeny than memory for verbal information, research concerning priming of nonverbal information is significant from evolutionary and ecological perspectives (e.g., Sherry & Schacter, 1987; Tulving & Schacter, 1990).

In a recent article, Schacter, Cooper, and Delaney (1990a) reported a series of experiments concerned with priming of newly acquired nonverbal information that does not have a preexisting memory representation (see also Bentin & Moscovitch, 1988; Gabrieli, Milberg, Keane, & Corkin, 1990; Kroll & Potter, 1984; Musen & Treisman, 1990). More specifically, Schacter et al. (1990a) developed a paradigm to examine implicit and explicit memory for novel three-dimensional objects. Target materials in these experiments were line drawings such as those displayed in Figure 1. All of the target objects are novel or unfamiliar in the sense that they do not represent actual objects that exist in the three-dimensional world. However, one half of the objects are structurally possible; their surfaces and edges are connected so that they could exist in three-dimensional form. The other half of the objects, in contrast, are structurally impossible and could not exist in three dimensions: They contain ambiguous lines and planes that create impossible relations between surfaces and edges within the figure (e.g., Draper, 1978; Penrose & Penrose, 1958).

To assess implicit memory for these objects, an object decision test was devised in which subjects, given 100-ms exposures to possible and impossible objects, decided whether each drawing was structurally possible or impossible (for a different type of object decision priming task, see Kroll & Potter, 1984). Schacter et al. (1990a) argued that accurate performance on the object decision test requires access to

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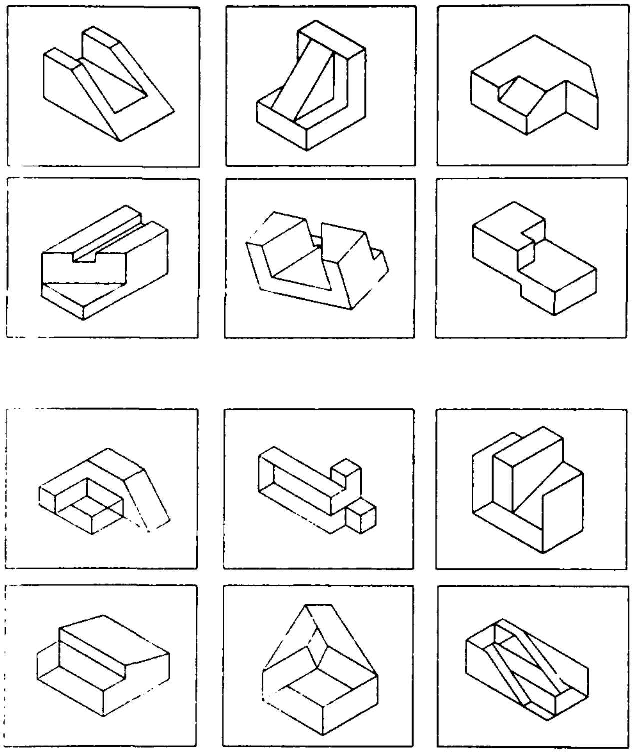

Figure 1. Representative examples of target objects. (The figures in the upper two rows depict structurally possible objects that could exist in three-dimensional form; figures in the lower two rows depict structurally impossible objects that could not exist in three-dimensional form.)

information about the global, three-dimensional structure of each object. In conformity with the principles of transfer-appropriate processing and encoding specificity (e.g., Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989; Tulving & Thomson, 1973), it follows that prior encoding of such information should produce priming on the object decision task. Pilot work indicated that without any prior exposure to the drawings, object decision accuracy was about 65% correct for both possible and impossible objects. To examine priming, one half of the drawings on the object decision test were presented to subjects on a prior study list, and the other half were new items that had not been previously presented. Priming in this paradigm is indicated by more accurate object decision performance for previously presented objects than for nonpresented objects. Explicit memory for the objects were assessed with a conventional yes/no recognition test.

An initial experiment yielded four noteworthy results. First, significant priming was observed after a study task that required encoding of information about the global three-dimensional structure of target objects (indicating whether each object faced primarily to the left or to the right), but no significant priming was found following a study task that required encoding of the local features of target objects (indicating whether each object had more horizontal than vertical lines). Second, priming was observed only for structurally possible objects; no priming was observed for structurally impossible objects. Third, the magnitude of priming for possible objects in the left/right encoding condition did not differ significantly when the object decision test was preceded by a recognition test in which all target objects were exposed, and when the object decision test alone was given. Fourth, priming showed stochastic independence from explicit memory—that is, the probability of recognizing a previously studied figure was uncorrelated with the probability of making a correct object decision about that figure (cf. Hayman & Tulving, 1989a; Tulving, Schacter, & Stark, 1982).

In a second experiment, implicit and explicit memory were compared after the left/right encoding task and an elaborative encoding task in which subjects were required to think of a familiar object from the real world that each drawing reminded them of most. Performance in the left/right condition provided a close replication of the results of the first experiment. As expected, the elaborative encoding task produced significantly higher recognition memory performance than did the left/right task. By contrast, there was no priming on the object decision task following elaborative encoding, thus indicating that implicit and explicit memory for novel objects can be dissociated experimentally. A subsequent experiment showed that significant object decision priming could be observed following elaborative encoding when the task ensured that subjects generated a three-dimensional elaboration for target objects by requiring them to classify each object into one of three categories of three-dimensional objects.

On the basis of these results, Schacter et al. (1990a) argued that priming on the object decision task depends on initial encoding of, and subsequent access to, a structural description (e.g., Marr, 1982; Marr & Nishihara, 1978; Palmer, 1975; Reed, 1974; Sutherland, 1968) of target objects—that is, a representation of the structural relations that define an object. It was argued further that this kind of information is handled by a presemantic structural description system (Riddoch & Humphreys, 1987) that is distinct from the episodic memory system that underlies explicit remembering of objects (see also Schacter, 1990). The structural description system, which can be viewed as one subsystem of a more general perceptual representation system (Schacter, 1990; Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990; cf. Johnson, 1983), is dedicated to the representation or retrieval of information about the form and structure of visual objects. This system is not, however, involved in the representation or retrieval of semantic information about objects—that is, functions that an object can perform or associative properties of an object, such as where it can be found or other objects to which it is functionally related.

Independent evidence for the existence of a structural description system has been provided by neuropsychological research on visual object agnosia that has shown that access to structural knowledge of objects can be preserved in patients whose access to functional and associative knowledge of objects is severely impaired (e.g., Riddoch & Humphreys, 1987; Warrington, 1982; Warrington & Taylor, 1978; see Schacter, 1990, for further discussion). Moreover, a good deal of research on visual perception has examined structural representations of objects, independent of their functional or associative properties (e.g., Biederman, 1987; Palmer, 1975; Sutherland, 1968; for review, see Pinker, 1984). With respect to the object decision task, the structural description hypothesis is consistent with the observed independence of implicit and explicit memory for novel objects and also accounts for the finding that priming does not require any semantic or elaborative study processing of target objects. This idea also suggests an interesting explanation for the failure to observe priming of impossible objects: It may be difficult and perhaps impossible to compute a structural description that preserves global, three-dimensional information about an impossible object. If forming a global representation of an impossible object exceeds the computational capacity of the structural description system, and object decision priming depends on gaining access to a previously encoded global description of an object, then it follows that priming of impossible objects will not be observed.

In this article we explore further priming of novel visual objects, with a view toward both elucidating the properties of the phenomenon and clarifying its theoretical implications. Experiment 1 examines the effects of repetition of structural encoding operations on object decision and recognition performance; it also assesses the idea that lack of priming for impossible objects reflects a limitation on the computational capacities of the structural description system by attempting to rule out various alternative explanations of the phenomenon. Experiment 2 explores the conditions under which structural descriptions are formed by assessing whether encoding objects from brief study exposures provides a basis for priming. Experiment 3 attempts to determine whether priming of possible objects can be increased, and priming of impossible objects observed at all, when subjects are induced to encode different types of structural information about target drawings. Experiment 4 investigates whether priming of impossible objects is observed when size differences among target objects are eliminated.

Experiment 1

The main purposes of Experiment 1 were twofold: (a) to assess alternative explanations of the failure to find priming of impossible objects, and (b) to replicate previous findings of priming for possible objects under different task conditions and delineate additional characteristics of the phenomenon.

Consider first the lack of priming for impossible objects. Although this phenomenon may reflect computational constraints on the structural description system, several other interpretations can be offered. One possibility discussed by Schacter et al. (1990a) concerns the criteria that were used to select target objects for inclusion in the initial experiments. In a pilot study, Schacter et al. gave 20 subjects unlimited time to judge whether candidate objects were possible or impossible; one half of the objects had been drawn to appear possible, and the other half had been drawn to appear impossible. An attempt was made to select as target items only those objects that yielded high levels of agreement across subjects. There was 97% agreement concerning the possible objects that were selected, but only 87% agreement concerning impossible objects. Failure to observe priming of impossible objects in the subsequent experiments may thus be attributable, at least in part, to the fact that there was relatively low agreement about whether these objects were indeed impossible. In fact, Schacter et al. noted that the object decision data for impossible objects showed marked fluctuation both within and between experiments and suggested that this unstable pattern might be related to the low intersubject agreement about impossible objects. To address this issue, we constructed a new and expanded set of possible and impossible objects and selected as target materials only those objects on which there was 95% or more intersubject agreement (see materials section of Experiment 1 for details).

A second potential reason for the lack of priming of impossible objects concerns the instructions and response requirements of the object decision task used in the earlier experiments. Specifically, instructions for the object decision test emphasized detection of possible objects; subjects were instructed to press one response key if an object "could be a possible object" and another response key if it "could not be a possible object." With these instructions, an impossible response was effectively a negative response. As discussed in the context of failures to observe priming of pseudowords or nonwords, lack of priming may sometimes be attributable to the influence of a negative response set (e.g., Feustel, Shiffrin, & Salasoo, 1983). Accordingly, we altered task instructions so that an *impossible* response was no longer defined explicitly as a negative response, and subjects were encouraged to process the impossible objects carefully.

A third issue is whether lack of priming for impossible objects was simply a consequence of generally weak or degraded memory for these objects. As noted earlier, explicit memory was consistently lower for impossible objects than for possible objects, thereby suggesting that the memory representation for impossible objects was simply not strong enough to support priming. This account seems unlikely in view of the fact that we observed stochastic independence between priming and explicit memory for possible objects. Nevertheless, we attempted to increase the likelihood of observing priming for impossible objects by including a condition in which subjects were given four successive exposures to the study list. On each exposure, they performed the left/right encoding task that has yielded priming of possible objects in previous studies. We expected that four repetitions of the left/right task would yield high levels of explicit memory for impossible objects. The question is whether priming of impossible objects will be observed under these conditions.

The repetition manipulation was also intended to provide further information concerning priming of possible objects. In our previous experiments, a second exposure to previously studied objects on a yes–no recognition test failed to produce more priming on the subsequent object decision test than did a single study exposure, hence suggesting that priming of possible objects may be insensitive to the number of prior exposures. However, a similar lack of priming was also documented in several experimental conditions when an object was first exposed on the recognition test (as a lure item). This latter finding suggests that the absence of test-induced priming may be attributable to the type of processing in which subjects engage on the recognition test and may not reflect some sort of general insensitivity of object decision priming to the number of prior exposures. Comparison of priming for possible objects following one versus four study exposures should illuminate the matter.

Method

Selection of target materials. In order to create a set of materials in which there was equivalent intersubject agreement concerning possible and impossible objects, a set of 50 possible and 50 impossible objects similar to those displayed in Figure 1 was created. All 50 impossible objects were drawn by one of the experimenters (S.M.D.). Of the 50 possible objects 40 were modified by the same experimenter from a set used originally by Cooper (1990), and 10 possible objects were taken directly from this latter set. Impossible objects all contained ambiguous lines and planes that produced impossible relations between surfaces and edges within the figure. Possible objects, on the other hand, did not have any ambiguities that suggested impossible relations among surfaces and edges; each plane in the figure depicted a surface, each line an edge.

To assess intersubject agreement, a pilot study was performed in which line drawings of the 50 possible and 50 impossible objects were randomly intermixed and shown to 20 subjects (University of Arizona undergraduate and graduate students); they were given unlimited time to classify each object as either possible or impossible. Objects were drawn in black outline on white 8-1/2 in. × 11 in. (21.59 cm × 27.94 cm) sheets and shown to subjects individually. Our criterion for considering an individual object for inclusion in the experimental set was an agreement rate of 95% or higher—that is, either 19 or 20 subjects had to classify a possible object as possible or an impossible object as impossible. We then created computer-generated line drawings of all objects, using a Compaq 386 Deskpro computer and 12 in. (30.48 cm) Princeton Ultrasync Monitor, randomly mixed them, and presented the drawings on an object decision test to a new sample of 20 undergraduates under the same conditions used in the experiments described later in this article. Specifically, each object was presented for 100 ms, followed by a darkened screen. The objects subtended a mean visual angle of 8° when viewed from 60 cm. The drawings were presented in medium resolution, and they appeared white against a uniform dark gray background. Presentation of each drawing was preceded by a fixation point that appeared in the middle of the screen. Subjects initiated presentation of the object by pressing the center key on a three-key personal computer (PC) mouse that they controlled with their right hand. Once the item appeared, subjects pressed either the left or the right response key to indicate whether the object was possible or impossible; one half of the subjects used the left key to indicate a possible response and the right key to indicate an impossible response; this response mapping was reversed for the other half of the subjects. A total of 10 practice items were presented at the 100-ms rate before presentation of the 100 critical items.

Subjects were told that they would be viewing a series of briefly exposed drawings and deciding whether each figure could actually exist in the real world. They were told that some of the drawings represented valid, possible three-dimensional objects that could exist in the world, whereas other drawings represented impossible figures that could not exist as three-dimensional objects in the real world, and that their task was to decide which objects were possible and which were impossible. Examples of possible and impossible objects were then shown to subjects. They were informed that all possible objects had to have volume and be solid, that every plane on the drawing represented a surface of the object, that all surfaces could face in only one direction, and that every line on the drawing necessarily represented an edge on the object. The experimenter then asked the subject to indicate why several sample impossible objects were impossible and explained the impossibilities to the subjects as needed. Subjects were then instructed in the use of a three-button mouse to make their responses and told to focus on the central fixation point before each trial.

In all, 20 possible and 20 impossible objects were selected for inclusion in the experimental set. As noted earlier, there was either 95% or 100% intersubject agreement about each selected object, yielding overall agreement rates of 99% for possible and impossible objects. In addition, we attempted to select objects that yielded an overall baseline classification rate of .60 to .65 in the 100-ms exposure condition, as in our previous experiments. The baseline rate was .61 for the selected possible objects and .64 for the selected impossible objects; baseline rates for individual objects ranged from .51 to .80.

Subjects. A total of 80 University of Arizona undergraduates participated in the main experiment in return for course credits or a payment of $5; 20 subjects were randomly assigned to one of the four between-subjects conditions.

Design. The main design consisted of a 2 (one vs. four study exposures) × 2 (object decision test vs. recognition test) × 2 (possible vs. impossible objects) × 2 (studied vs. nonstudied drawings) mixed factorial. The first two factors, number of study exposures and type of test, were between-subjects variables; the latter two factors, object type and item type, were within-subjects variables. In addition, the object decision test was either given alone or after the recognition test, thus creating a test order variable for the object decision analysis.

The target set of 20 possible and 20 impossible objects described earlier was randomly divided into two subsets, A and B. Each subset consisted of 10 possible and 10 impossible objects. The experiment was completely counterbalanced so that each subset appeared equally often as studied and nonstudied drawings in the main experimental conditions.

Procedure. All subjects were tested individually under conditions of incidental learning: They were told that the experiment concerned object perception, and no mention was made of any subsequent memory test. Subjects in both the one- and the four-exposure groups were told that a series of drawings would appear on the computer monitor for 5 s, and that their task was to judge whether each object appeared to be facing primarily to the left or primarily to the right. Subjects were told to use the entire 5 s to inspect each object carefully and to make an accurate left/right judgment because the objects were often not as simple as they appeared. The task began with the presentation of 5 practice items, followed by the presentation of the 10 possible and 10 impossible target objects in random order. For the four-exposure group, the study list was presented three more times after the initial exposure, each time in a different random order.

Immediately after the study list presentation, one half of the subjects were given the instructions for the object decision test described earlier, and the other half were given instructions for the recognition test. The object decision instructions included three modifications of the instructions used by Schacter et al. (1990a). First, to reduce the likelihood that the previous failure to observe priming of impossible objects is attributable to inadequate comprehension of what constitutes an impossible object, the instructions were modified to include different examples of structural impossibility and subjects were required to point out specifically the impossible aspects in several impossible objects. Second, instead of being told to press one response key if a drawing could be a possible object and another if it could not be a possible object, subjects were instructed to press one response key if a drawing appeared to be a possible object and another key if the drawing appeared to be an impossible object. Third, whereas in the previous experiments we used a randomly determined response mapping (subjects pressed the left key for "could be possible" and right key for "could not be possible"), in the present study we counterbalanced response mappings. One half of the subjects in each experimental condition pressed the left key to indicate a possible response and the right key to indicate an impossible response, whereas the reverse response mapping was used for the other half of the subjects.

Administration of object decision instructions took approximately 2 min. The object decision test was then given, with studied and nonstudied objects appearing for 100 ms under the same conditions described earlier with respect to the baseline study. The test began with 10 practice drawings, 5 that had appeared on the study list and 5 that had not appeared on the study list. These were followed in an uninterrupted sequence by the 20 studied and 20 nonstudied target drawings. Each test trial was initiated by the appearance of a fixation point in the middle of the computer screen.

Subjects who were given the yes/no recognition test were told that they would be shown a series of drawings, some of which had just been presented during the study task and some of which had not been shown previously. These subjects were further instructed to press one response key if they remembered seeing the object during the left/right encoding task and another response key if they did not remember seeing the object. response mappings were counterbalanced so that the left and the right keys were used equally often for yes and no recognition responses. As in the object decision test, each test trial was initiated upon the appearance of the fixation point.

The same 10 practice items that were used on the object decision test (5 studied, 5 not studied) were presented initially, followed by presentation of 20 studied and 20 nonstudied target drawings in random order. About 2 min intervened between conclusion of the study task and appearance of the first practice item. Drawings remained on the computer screen for 5 s, until subjects made their recognition responses. The recognition test was generally completed in about 3 to 4 min. Immediately after conclusion of this test, subjects were given the same object decision instructions and test described earlier.

After the conclusion of testing, all subjects were debriefed concerning the nature of the experiments.

Results

Object decision. The object decision data are displayed in Table 1. Consider first the findings in the one-study-exposure condition. Overall, these results provide a close replication of the critical patterns of data reported by Schacter et al. (1990a). Object decision accuracy was higher for studied than for nonstudied possible objects, thereby indicating the presence of priming; in contrast, there was no evidence of priming for impossible objects. Performance was similar whether the object decision test was given first or second (after the recognition test), although the difference between studied and nonstudied possible objects was greater in the first than in the second test condition. Note that a virtually identical pattern of results was observed in the four-exposure condition: There was robust priming for possible objects and no difference between studied and nonstudied impossible objects, both when the object decision test was given first and when it was given second. Performance was higher for impossible objects in the second than in the first test condition, but as indicated later, this trend was not statistically significant.

A preliminary analysis of variance (ANOVA) was performed that included response mapping as a factor, and no main effects or interactions approached significance (all $Fs < 1$). Accordingly, all subsequent analyses were collapsed across this variable. The key outcome of the ANOVA was a significant interaction of Object Type (possible vs. impossible) × Item Type (studied vs. nonstudied), $F(1, 76) = 17.86$, $MS_e = .017$, $p < .001$, indicating that priming was observed for possible but not for impossible objects. The main effect of study exposures was not significant $F(1, 76) < 1$, and this variable did not enter into any significant interactions (all $Fs < 1.90$). Similarly, there was a nonsignificant main effect of test order $F(1, 76) = 1.18$, $MS_e = .098$, and test order did not interact with any other variable (all $Fs < 2.81$).[1]

Recognition memory. The recognition data (hits and false alarms), presented in Table 2, contrast sharply to the object decision data: Explicit memory was considerably higher after four than after one study exposure for both possible and impossible objects. An ANOVA was performed on the hit rates in the main experimental conditions, and also on a corrected recognition measure (hit rate minus false alarm rate). These two types of analyses led to identical conclusions, indicating that the false alarm rate was relatively constant across experimental conditions. We therefore report the results of the hit rate analysis only.

The ANOVA revealed a highly significant main effect of study exposures, $F(1, 38) = 16.87$, $MS_e = .057$, $p < .001$. There was also a main effect of object type, $F(1, 38) = 6.51$, $MS_e = .017$, $p < .02$, reflecting the fact that recognition memory was more accurate for possible than for impossible objects. The Object Type × Study Exposures interaction was not significant, $F(1, 38) = 2.34$, $MS_e = .017$.

The foregoing analyses suggest that number of study exposures affects recognition but not object decision performance. Two ANOVAs that included type of test as a variable were performed on studied items (i.e., proportion correct for object decision and hit rate for recognition). The first compared recognition and object decision performance, with type of test as a within-subjects variable, and revealed a significant Study Exposures × Type of Test interaction, $F(1, 38) = 7.27$, $MS_e = .050$, $p < .01$. The second ANOVA compared recognition and first test object decision performance, with type of test as a between-subjects variable. It also showed a highly significant Study Exposures × Type of Test interaction, $F(1, 76) = 13.65$, $MS_e = .053$, $p < .001$. These interactions confirm that the one- versus four-exposure manipulation influenced recognition but not object decision performance.

To examine further the relation between object decision and recognition performance, we performed contingency analyses to determine whether priming and recognition of possible objects exhibits stochastic independence, as was observed in our earlier article. Only the data from the one-exposure condition were considered because there were too few recognition errors in the four-exposure condition to per-

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[1]This ANOVA and all others in this article were performed on data from individual subjects and not from individual items. However, because a restricted item set was used in the present experiments and because type of item (i.e., possible vs. impossible) was a factor, it is important to know whether the results hold across items as well as across subjects. Analysis of the data across items revealed the same patterns as were observed across subjects, but only the subject-based analyses are reported.

Table 1
Object Decision Performance: Experiment 1

	Number of study exposures/test order					
	One exposure			Four exposures		
Item type	First	Second	*M*	First	Second	*M*
Possible objects						
Studied	.76	.72	.74	.71	.71	.71
Nonstudied	.57	.65	.62	.56	.60	.58
M	.66	.69	—	.64	.66	—
Impossible Objects						
Studied	.68	.66	.67	.61	.72	.67
Nonstudied	.67	.68	.68	.59	.71	.65
M	.68	.67	—	.60	.72	—

Note. Each study exposure consisted of a 5-s left/right judgment.

mit a meaningful contingency analysis. We constructed 2 × 2 contingency tables in which each of the four cells represent the probability of the joint outcome of success or failure on successive recognition and object decision tests for studied possible objects. The contingency analysis indicated that the conditional probability of a correct object decision being given successful recognition (.73) was essentially identical to the overall probability of a correct object decision (.72), thereby indicating independence between the two tests. These data replicate our earlier findings of independence with a new set of materials and different test instructions. Issues concerning the analysis and interpretation of stochastic independence will not be discussed further in this article (see Schacter et al., 1990a, for more extensive analysis and discussion of stochastic independence between recognition and object decision, and Hayman & Tulving, 1989a, for more general discussion).

Discussion

Experiment 1 yielded three new results concerning implicit and explicit memory for novel visual objects. First, there was no priming on the object decision task for structurally impossible objects even following four study exposures. Second, significant and comparable amounts of object decision priming were observed for structurally possible objects after one and four study exposures. Third, recognition performance was significantly higher in the four- than in the one-study exposure condition for both possible and impossible objects.

Table 2
Recognition Performance: Experiment 1

	Number of study exposures		
Item type	One	Four	*M*
Possible objects			
Studied	.65	.91	.78
Nonstudied	.24	.21	.23
Impossible objects			
Studied	.62	.80	.71
Nonstudied	.29	.18	.24

Note. Studied = proportion of studied items called *old* (hit rate). Nonstudied = proportion of nonstudied items called *old* (false alarm rate). Each study exposure consisted of a 5-s left/right judgment.

These results confirm our previous findings on object decision priming and provide additional evidence that implicit and explicit memory for novel visual objects can be dissociated experimentally. In addition, we replicated our previous findings of stochastic independence between object decision and recognition performance.

The fact that we did not observe any evidence of priming for structurally impossible objects under the present experimental conditions extends our previous observations and helps to rule out several interpretations of these findings. Whereas in the earlier experiments there was relatively low intersubject agreement under unlimited viewing conditions that impossible objects are indeed impossible (.87), there was near-complete intersubject agreement (.99) that the present set of impossible objects are impossible. Accordingly, lack of priming cannot be attributed to low intersubject agreement about the impossible nature of these figures. Our results also provide evidence against the idea that no priming of impossible objects is observed because impossible responses are treated as negative responses. Although, as discussed earlier, the task instructions in our previous experiments did effectively turn impossible responses into negative responses, the instructions in the present study were altered so that this was no longer the case. In addition, mappings between response keys and possible or impossible responses were counterbalanced in this experiment instead of being randomly assigned, as they were in the earlier studies. Despite these procedural modifications, we replicated our previous findings of no priming for impossible objects.

Our data also provide evidence against the idea that the memory representation of impossible objects is simply too weak to support priming. As in previous experiments, recognition memory for possible objects was higher than for impossible objects. The critical data, however, emerge from a comparison of performance for possible objects after a single exposure and impossible objects after four study exposures. Even though recognition of impossible objects after four exposures was considerably higher than recognition of possible objects after a single exposure (Table 2), priming was observed in the latter but not in the former condition. Thus, even under conditions in which the explicit memory data suggest a strong episodic representation of impossible objects—one that supports higher levels of recognition performance than does the episodic representation of possible objects—we still failed to observe priming for impossible objects. Nevertheless, we have not of course ruled out the possibility that significant priming of impossible figures on an object decision task could be demonstrated under some set of conditions. We will explore further issues concerning priming of impossible objects in Experiments 3 and 4.

An additional issue that merits brief commentary concerns the possible role of response bias in the priming effects that we observed. It is conceivable that exposure to objects during the left/right study task simply produces a generalized bias to make a possible response to all previously studied items on the object decision test—possible and impossible—thus producing priming of possible but not of impossible objects. We considered this issue at length in our previous study (Schacter et al., 1990a) and showed that response bias could not account for the priming that we observed following the left/right encoding task. To evaluate the role of response bias in the present data, we used the same measure that was used by Schacter et al. (1990a): Yule's Q, a special case of the gamma correlation for analyzing association in 2×2 contingency tables (See Goodman & Kruskal, 1954; Hayman & Tulving, 1989a, 1989b; Nelson, 1984, 1990). Q provides an estimate of the strength of relation between two variables that can vary from -1 (negative association) to $+1$ (positive association). We created 2×2 contingency tables for each subject in which the four cells were defined by the orthogonal combination of subjects' responses (possible/impossible) and object type (possible—impossible). We then computed Qs separately for studied and for nonstudied items according to procedures described by Nelson (1984, 1990) and Reynolds (1977). The larger the Q value within an experimental condition, the greater the strength of association between subjects' responses and object type—that is, a more positive Q value indicates more accurate object decision performance. The question for our purposes is whether the Q for studied objects is larger than the Q for nonstudied objects. If priming reflects an increase in the accuracy of object decision performance for studied objects relative to nonstudied objects—and not some sort of generalized bias to use the possible response more frequently for studied than for nonstudied objects—then the Q value for studied items should be higher than the Q value for nonstudied items. If, on the other hand, priming simply reflects a study-induced response bias to say possible to old items (both possible and impossible), then Q values should not differ for studied and nonstudied items. In the single-exposure condition, the Q value for studied items (+.56) was significantly higher than the Q value for nonstudied items +.41; $t(38) = 2.18$, $p < .01$; the same pattern of results was observed in the four-exposure condition, studied $Q = +.55$, nonstudied $Q = +.31$; $t(38) = 3.73$, $p < .01$. These results show that object decision performance was more accurate for studied than for nonstudied items. (The fact that positive Q values were obtained even for nonstudied items simply indicates that baseline performance on the object decision task exceeds chance levels of accuracy.) Accordingly, these data indicate that the priming that we observed cannot be attributed to a generalized bias to use the possible response more frequently for studied objects than for nonstudied objects.

The foregoing analyses are thus consistent with the proposal that priming of possible objects is mediated by newly acquired structural descriptions of target drawings. Viewed from this perspective, the failure to find an effect of number of study exposures on priming—despite large effects on explicit memory—suggests that a single 5-s left/right judgment about a possible object is sufficient to establish a structural description that preserves the sort of global, three-dimensional information that supports object decision priming. We have thus far used a 5-s-exposure duration because we think that the analyses entailed in computing a global structural description—determining depth relations among surfaces and edges, assessing the orientation of the object in space, and so on—require some time to be completed. Thus, our encoding instructions have emphasized that subjects should use the full 5 s to inspect each object carefully before making a left/right judgment, and we have assumed that it is important for subjects to make use of this time in order to observe priming. It is conceivable, however, that object decision priming does not require such extensive structural analysis and that even a snap left/right judgment is sufficient to support priming.

To examine this issue and to provide more information about the kinds of encoding activities that are needed to support priming of novel visual objects, we examined object decision performance following two different study conditions in Experiment 2. One group of subjects made left/right judgments on the basis of a single 1-s exposure to each object. If priming is observed in this condition, it would indicate that the structural analyses required to support object decision priming require considerably less time and are perhaps less extensive than we had initially supposed. A second group of subjects was given five successive 1-s exposures to target objects—as much total exposure time as subjects in previous experiments who were given a single 5-s exposure.

The implications of the priming data in this latter condition depend to some extent on the results in the single 1-s exposure condition. If significant priming is observed following a 1-s exposure, then we will be in a position to assess the generality of the finding from Experiment 1 that repetition beyond a single exposure fails to increase the magnitude of priming. On the other hand, if no priming is observed following a single 1-s exposure, then a failure to find priming following five 1-s exposures would suggest that object decision priming is largely or entirely immune to the effects of repetition. If, however, significant priming is observed following five 1-s exposures—even though no priming is found after a single 1-s exposure—there would be evidence that object decision priming could benefit from repetition and that structural representations could be formed on the basis of temporally distributed encoding operations.

Experiment 2

Method

Subjects. A total of 80 University of Arizona undergraduates participated in the experiment in exchange of class credits; 20 subjects were assigned randomly to each of the four between-subjects conditions in the experiment.

Design, materials, and procedure. The same set of 20 possible and 20 impossible objects that was used in Experiment 1 constituted the target materials. The design of the experiment consisted of two between-subjects variables, study exposures (one vs. five) and type of test (object decision vs. recognition), and two within-subjects variables, object type (possible vs. impossible) and item type (studied vs. nonstudied). The object decision test was either given first or second (after the recognition test), thus creating a test order variable for the object decision analysis.

The study and test instructions as well as the procedures used in Experiment 2 were identical to those described in Experiment 1, with two exceptions. In the single-exposure condition, objects appeared on the computer monitor for 1 s, and subjects then made their left/right decision. In the five-exposure condition, the same 1-s presentation rate was used, except that subjects were given five successive exposures to the study list; objects were presented in a random order on each pass through the list, and subjects made a left/right judgment on each exposure to an object.

Results

Object decision. The object decision data are presented in Table 3. First, consider the results for structurally possible objects. In the single-exposure condition, object decision accuracy was virtually identical for studied and nonstudied items in both the first and second test conditions. By contrast, in the five-exposure condition, object decision accuracy was greater for studied than for nonstudied objects on both tests. There was no evidence of priming for structurally impossible objects in any experimental condition.

An overall ANOVA that included study condition as a between-subjects variable revealed a significant main effect of object-type (possible vs. impossible), $F(1, 76) = 7.03$, $MS_e = .053$, $p < .01$, and a marginally significant Object Type × Item Type (studied vs. nonstudied) interaction, $F(1, 76) = 3.93$, $MS_e = .022$, $p = .053$, indicating that priming was observed for possible but not for impossible objects. There was also a significant Study Condition × Object Type interaction, $F(1, 76) = 4.69$, $MS_e = .053$, $p < .05$. This interaction indicates that object decision performance for possible objects was more accurate after five exposures than after one exposure—presumably because of priming effects in the former but not in the latter condition—whereas performance for impossible objects was comparable in the two conditions. However, the Study Condition × Object Type × Item Type interaction was not significant, $F(1, 76) = 1.92$, $MS_e = .023$. No other main effects or interactions were significant (all $Fs < 2.55$).

Separate ANOVAs were performed for the one-exposure and for the five-exposure conditions. In the one-exposure condition, there was a trend for priming of possible but not for impossible objects from the recognition test: Object decision accuracy was higher in the second than in the first test condition for both studied and for nonstudied possible objects. However, neither the main effect of test order nor any interactions involving test order were significant ($Fs < 2.18$). No other effects were significant (all $Fs < 1$).

In the five-exposure condition, there was a significant effect of object type, $F(1, 38) = 18.59$, $MS_e = .033$, $p < .001$. More important, there was a significant Object Type × Item Type interaction, $F(1, 38) = 6.61$, $MS_e = .019$, $p < .02$, indicating that priming was observed for possible but not for impossible objects. No other main effects or interactions were significant, all $Fs < 1.63$.

Recognition. Recognition accuracy was considerably greater in the five-exposure condition than in the single-exposure condition, and there was also a trend for greater recognition accuracy of possible than of impossible objects. An ANOVA performed on the hit rates revealed a highly significant main effect of study condition, $F(1, 38) = 14.90$, $MS_e = .045$, $p < .001$. The main effect of object type approached but did not attain significance, $F(1, 38) = 2.83$, $MS_e = .032$, $P = .10$, and the Study Condition × Object Type interaction was not significant, $F(1, 38) = 1$. An analysis of corrected recognition scores (hits minus false alarms) revealed a similar pattern of results, except that now the effect of object type was significant, $F(1, 38) = 6.84$, $MS_e = 0.40$, $p < .02$.

Discussion

Experiment 2 has shown that priming of structurally possible objects is observed after five 1-s left/right judgments, but not after a single 1-s left/right judgment. The failure to observe priming in the single 1-s exposure condition indicates that several seconds are required to perform the encoding operations necessary to build a structural description of a novel object that is sufficient to support priming on the object

Table 3
Object Decision Performance: Experiment 2

	Number of study exposures/test order					
	One exposure			Five exposures		
Item type	First	Second	*M*	First	Second	*M*
Possible objects						
Studied	.60	.72	.66	.75	.80	.78
Nonstudied	.59	.71	.65	.64	.73	.68
M	.60	.71	—	.70	.77	—
Impossible objects						
Studied	.62	.65	.64	.57	.61	.59
Nonstudied	.62	.67	.64	.62	.61	.62
M	.62	.66	—	.60	.61	—

Note. Each study exposure consisted of a 1-s left/right judgment.

decision task. (It is of course conceivable that a 1-s exposure would be sufficient to support priming of novel objects on an implicit test other than object decision.) This result is also consistent with the finding in the present experiments and those of Schacter et al. (1990a) that the appearance of studied or nonstudied objects on a recognition test does not produce robust priming. Test priming effects have generally been either weak or absent in most experimental conditions, although there was a trend for test priming in the single-exposure condition of Experiment 2, and a similar trend was observed when performance was assessed at long delays (see Schacter, Cooper, & Delaney, 1990b). However, the fact that significant test priming has not been observed makes good sense in view of the fact that subjects' recognition latencies are generally on the order of 1 to 1.5-s in our experiments. The lack of priming in the 1-s-exposure condition and the failure to observe consistent test priming effects suggest that priming on the object decision tests depends on careful and extensive structural analysis of an object at the time of study. If appropriate structural analyses are not performed, either because the task does not require them or because insufficient time is given to perform the necessary computations, object decision priming apparently will not be observed.

The foregoing considerations suggest that a 5-s left/right judgment allows subjects to encode the various kinds of structural information about an object that are needed to facilitate subsequent object decision performance. The fact that significant priming was observed following five 1-s exposures suggests that some of the necessary structural information can be acquired from successive and temporally separate brief exposures to an object. These considerations, when coupled with the finding from Experiment 1 that four 5-s exposures do not produce more priming than a single 5-s exposure, suggest that when an adequate or complete structural description has been formed on the basis of a 5-s left/right judgment, further repetitions are redundant and do not add to priming. However, when an incomplete structural description has been formed on the basis of a 1-s exposure, further repetitions are beneficial, perhaps because they allow the necessary structural information to be acquired.

It is important to note, however, that the overall magnitude of the priming effect after five 1-s exposures is somewhat smaller than the priming effects observed after one or four 5-s exposures condition in Experiment 1. Indeed, when we performed the Q analysis described in Experiment 1, we found that the Q value for studied objects (+.52) was higher than for nonstudied objects (+.46), but we also found that the difference did not achieve statistical significance, $t(38) < 1$. This analysis suggests that the component of priming attributable to a newly acquired structural description—as opposed to response bias—may be less robust after five 1-s exposures than after a single 5-s exposure and, hence, that a single 5-s exposure may produce a more useful or complete structural description than five separate 1-s exposures. However, it is not entirely clear whether a nonsignificant difference between Qs for studied and for nonstudied objects signals that priming should be attributed to response bias (see discussion of Experiment 3), so it is probably reasonable to conclude that priming in the five 1-s exposures condition is based at least in part on a stored structural description. Note that explicit memory was considerably higher following five 1-s exposures than following a single 5-s exposure (as is indicated by comparing data in Table 4 and Table 2), thus indicating again that implicit and explicit memory for novel objects can be dissociated experimentally.

Experiment 3

Experiments 1 and 2 suggest that a 5-s left/right judgment may be sufficient to encode a reltively complete structural description of an object, at least with respect to the demands of the object decision test. However, the repetition manipulations used in these experiments involved performing the same encoding operations (i.e., left/right judgment) on each exposure to target objects. This kind of repetition may have provided redundant structural information about the objects and, hence, did not increase the size of the priming effect (although the same repetition manipulation did improve explicit memory). Thus, it is possible that priming could be enhanced if, in addition to the left/right task, subjects performed a different encoding task that yielded nonredundant structural information about studied objects.

To examine this issue, we compared priming in the left/right condition with priming in a condition in which subjects performed both the left/right task and a three-dimensional classification task. In the three-dimensional classification task, subjects are asked to classify each target object in terms of which of three categories of real-world, three-dimensional objects the target would best fit: type of furniture, household object, or type of building. In previous research (Schacter et al., 1990a) we found that the three-dimensional classification task produced significant priming effects on the object decision test. Because this task supports priming, we assume that it provides a basis for establishing a three-dimensional structural description of an object. However, the encoding operations required by this task differ at some level from the encoding operations required by the left/right task. Performing both the left/right and three-dimensional classification tasks (we will refer to this task as the *left/right+* condition), then, should add nonredundant information to the encoded representation of target objects. The question is whether this information is useful for the object decision test and thus increases the magnitude of priming.

Table 4
Recognition Performance: Experiment 2

Item type	Number of study exposures: One	Five	*M*
Possible objects			
Studied	.60	.77	.68
Nonstudied	.28	.10	.19
Impossible objects			
Studied	.52	.72	.62
Nonstudied	.31	.19	.25

Note. Studied = proportion of studied items called *old* (hit rate). Nonstudied = proportion of nonstudied items called *old* (false alarm rate). Each study exposure consisted of a 1-s left/right judgment.

In Experiment 3 we also explore further whether priming of impossible objects can be observed. The left/right+ condition should provide useful information in this regard because it will allow us to determine whether performing two different types of structural encoding tasks supports priming of impossible objects. Moreover, we have already observed a trend for priming of impossible objects following the three-dimensional classification task alone (Schacter et al., 1990a, Experiment 3, object decision first condition).

We also modified our materials and paradigm in an attempt to produce equivalent levels of baseline performance for possible and impossible objects. A potentially problematic feature of Experiment 1 is that baseline levels of performance for nonstudied possible objects were consistently lower than for nonstudied impossible objects (see Table 1). Stated slightly differently, there was a bias to use the impossible response more frequently than the possible response for nonstudied items. (This trend was also evident in the first test object decision data from Experiment 2, but it was not apparent in the second test data.) By contrast, in our previous experiments using the left/right task (Schacter et al., 1990a, Experiments 1 and 2), performance on nonstudied items was nearly identical for possible and for impossible objects.

Because comparison of the relative amounts of priming for possible and impossible objects can be made most readily when equivalent baselines are obtained, it would be desirable to replicate the results of Experiment 1 under conditions in which baseline performance for possible objects is higher than was observed in Experiment 1 and, hence, more nearly equivalent to the baseline level for the impossible objects. To achieve this objective, we made two small changes in our experimental paradigm. First, we used the set of possible objects from the Schacter et al. (1990a) study, which generally yielded higher levels of baseline performance than did the possible object set used in Experiments 1 and 2. Second, we explicitly informed subjects that one half of the figures on the object decision test were possible and the other half were impossible; in previous experiments we had simply indicated that some objects would be possible and that some would be impossible. We reasoned that providing this information would reduce the likelihood of any generalized bias to use the impossible response more often than the possible response.

Method

Subjects. A total of 80 University of Arizona undergraduates participated in the experiment in return for course credits.

Materials, design, and procedure. The critical items consisted of the 20 impossible objects from Experiments 1 and 2 and the 20 possible objects used in Schacter et al. (1990a). As noted earlier, this set of possible objects yielded generally higher levels of baseline performance than did the possible objects used in Experiments 1 and 2, and these baseline levels were nearly equivalent to those obtained with the impossible objects.

The main design consisted of a 2 × 2 × 2 × 2 mixed factorial, with two between-subjects variables (left/right vs. left/right+ encoding and object decision vs. recognition test) and two within-subjects variables (studied vs. nonstudied items and possible vs. impossible objects). In addition, the object decision test was either given alone or after the recognition test, thereby creating a test order variable for the object decision analysis. For the left/right+ encoding task, one half of the subjects performed left/right judgments on all target objects and then performed the three-dimensional classification task on the same objects; the other half of the subjects performed the elaborative classification task first and the left/right task second. Possible and impossible objects were each randomly divided into two subsets of 10 items, and the subsets were completely counterbalanced across experimental conditions.

In the left/right condition, task instructions and item presentations were the same as those described in Experiments 1 and 2. In the left/right+ condition, one half of the subjects were first given left/right encoding instructions and then were given 5 s to make left/right judgments about all target objects. After making left/right judgments for all studied objects, these subjects were then told that they would be shown the same objects again, but would be asked to make a different judgment. They were instructed to classify each object into one of three categories, depending on what the object most reminded them of: a type of furniture, a household object, or a type or part of a building. They were further asked to generate a specific exemplar from the category that was chosen (e.g., a desk, a bottle, or a wall); 5 s were allowed for each classification. The other half of the subjects in the left/right+ condition performed the three-dimensional classification task first and the left/right task second.

One half of the subjects in the left/right and left/right+ conditions were then given either the object decision test or the recognition test; subjects in the latter condition were given the object decision test after the recognition test. All aspects of testing were the same as described in previous experiments.

Results

Object decision. Consider first the results from the left/right condition (see Table 5). These data replicate the major trend observed in previous experiments—robust priming for possible but not for impossible objects—under conditions in which the overall baseline levels of performance for the two types of objects are virtually identical (.63 for possible objects and .62 for impossible objects). In the left/right+ encoding condition, the magnitude of priming for possible objects was about the same as in the left/right condition, and there was no evidence for priming of impossible objects; in fact, there was a trend for less accurate classification of studied than of nonstudied impossible objects in both the first and second test conditions (see Discussion section). There was no clear evidence of test-induced priming in either encoding condition.

An ANOVA revealed main effects of both item type (studied vs. nonstudied), $F(1, 76) = 4.67$, $MS_e = .023$, $p < .05$, and object type (possible vs. impossible), $F(1, 76) = 17.55$, $MS_e = .027$, $p < .001$. There was also a significant interaction between these two variables, $F(1, 76) = 25.26$, $MS_e = .018$, $p < .001$, thus confirming that priming was observed for possible but not for impossible objects. There was also an unanticipated Test Order × Object Type × Item Type interaction, $F(1, 76) = 5.12$, $MS_e = .018$, $p < .05$, indicating that the magnitude of priming for possible objects relative to impossible objects was greater when the object decision test was given first than when it was given second. We have not observed such an interaction previously in similar experiments, and we will not discuss it further.

The main effect of encoding condition was nonsignificant, $F(1, 76) < 1$, and this variable did not enter into any signifi-

Table 5
Object Decision Performance: Experiment 3

	Type of encoding task/test order					
	Left/right			Left/right+		
Item type	First	Second	*M*	First	Second	*M*
Possible objects						
Studied	.80	.69	.75	.80	.78	.79
Nonstudied	.66	.60	.63	.64	.71	.67
M	.73	.65	—	.72	.75	—
Impossible objects						
Studied	.67	.62	.65	.65	.60	.63
Nonstudied	.67	.57	.62	.74	.68	.71
M	.67	.60	—	.70	.64	—

Note. Subjects in the left/right condition were given 5 s to make a left/right judgment; subjects in the left/right+ condition were given 5 s to make a left/right judgment and 5 s to make a three-dimensional classification judgment.

cant interactions (all $Fs < 3.01$). No other main effects or interactions were significant.

Recognition. The recognition data are presented in Table 6. In contrast to the object decision results, type of encoding condition had a large effect on recognition performance: Explicit memory was much more accurate in the left/right+ condition than in the left/right condition. An ANOVA performed on the hit rates revealed significant main effects of encoding condition, $F(1, 38) = 41.04$, $MS_e = .029$, $p < .001$, and object type, $F(1, 38) = 4.70$, $MS_e = .018$, $p < .05$, with no interaction between these two variables, $F(1, 38) < 1$. When the same analysis was performed on hit rates minus false alarm rates, a highly significant effect of encoding condition was again observed, $F(1, 38) = 40.44$, $MS_e = .052$, $p < .001$, and the Encoding Condition × Object Type interaction was nonsignificant, $F(1, 38) < 1$. However, the main effect of object type failed to reach significance in this analysis, $F(1, 38) = 2.38$, $MS_e = .036$, thus indicating that the difference between recognition of possible and impossible objects was not robust in the present experiment.

Two further analyses were performed that included type of test (object decision vs. recognition) as a between-subjects variable (the results of these analyses were the same when hit rate and hit rate minus false alarm rate were used for the recognition data, so only the hit rate analyses are reported). For the first analysis, in which type of test was a between-subjects variable, the critical outcome was a significant Encoding Condition × Type of Test interaction, $F(1, 76) = 12.82$, $MS_e = .053$, $p < .001$. For the second analysis, in which Type of Test was a within-subjects variable, a similar Encoding Condition × Type of Test interaction was observed, $F(1, 76) = 11.14$, $MS_e = 0.42$, $p < .01$. These analyses confirm that recognition but not object decision performance was influenced by the encoding task manipulation.

Table 6
Recognition Performance: Experiment 3

	Type of encoding task		
Item type	Left/right	Left/right+	*M*
Possible objects			
Studied	.70	.94	.82
Nonstudied	.23	.17	.20
Impossible objects			
Studied	.63	.88	.76
Nonstudied	.25	.15	.20

Note. Studied = proportion of studied items called *old* (hit rate). Nonstudied = proportion of nonstudied items called *old* (false alarm rate). Subjects in the left/right condition were given 5 s to make a left/right judgment; subjects in the left/right+ condition were given 5 s to make a left/right judgment and 5 s to make a three-dimensional classification judgment.

Discussion

The left/right+ condition greatly enhanced explicit memory for possible and impossible objects relative to the left/right encoding task alone. Nevertheless, we still failed to observe any evidence for priming of impossible objects in the left/right+ condition, and priming of possible objects was no greater in the left/right+ condition than in the left/right condition. In addition, we observed priming of possible but not impossible objects under conditions in which baseline levels of object decision accuracy were essentially identical for the two types of objects.

With respect to the possible objects, our data are consistent with the idea that the encoding operations performed during a 5-s left/right judgment allow subjects to form a relatively complete structural description of a novel object with respect to the demands of the object decision test. The results of an earlier experiment (Schacter et al., 1990a, Experiment 3) showing significant priming following the three-dimensional classification task indicate that similar conclusions also apply to this task. With respect to the impossible objects, the absence of priming in the left/right+ condition provides further evidence that the general failure to observe priming for these objects is not simply a function of some sort of generally weak memory representation because explicit memory for impossible objects was quite robust in the left/right+ condition. These results also indicate that performing two nominally different structural encoding tasks apparently does not produce a global structural description of an impossible object that can support object decision priming

The foregoing points should be considered in light of one possibly problematic feature of our data: the trend toward less accurate object decision performance on studied than on nonstudied impossible objects in the left/right+ condition (see Table 5). This trend suggests that the left/right+ condition may have produced a strong response bias to call all previously studied objects *possible*. The observed priming for possible objects and lack of priming for impossible objects may thus be partly or entirely attributable to this response bias. To assess the issue, we computed Yule's Q for studied and nonstudied objects in both the left/right+ and left/right conditions. Not surprisingly, in the left/right+ condition, Q for studied objects (+.57) and nonstudied objects (+.55) did not differ significantly, $t(39) < 1$. By contrast, in the left/right condition, Q for studied objects (+.64) was significantly higher than Q for nonstudied objects (+.51), $t(39) = 1.67$, $p < .05$.

Although this analysis suggests that priming of possible objects in the left/right+ condition is largely attributable to a bias to use the possible response more frequently for all studied objects (possible and impossible) than for nonstudied objects, we think that there are both logical and empirical grounds on which to question this conclusion. The logical argument follows from the previously established experimental fact that the left/right and three-dimensional classification tasks, when performed separately, each produce priming of possible objects that is not attributable to response bias: Q for studied objects is significantly higher than Q for nonstudied objects in both tasks (Schacter et al., 1990a, and Experiments 1 and 3 of the present article). Because each of these tasks produces significant structurally based priming when performed alone, it makes little sense to conclude that they do not produce significant structurally based priming when performed successively.

An empirical argument against the notion that priming in the left/right+ task is largely or entirely attributable to a study-induced bias to use the possible response emerges from consideration of assumptions underlying the analysis of response bias in our experimental paradigm. Specifically, a response bias to say *possible* to studied objects is assumed to operate when subjects provide more possible responses to studied than to nonstudied possible objects and provide more possible responses to studied than to nonstudied impossible objects. It is this latter tendency that takes the form of what we will call *negative priming* of impossible objects—lower object decision accuracy for studied than for nonstudied impossible objects. The key question is whether it is necessary to assume that such a trend in the impossible object data indicates the presence of bias in the possible object data. If this assumption were correct, then a simple empirical consequence would follow: The magnitude of priming effects for possible objects should be correlated significantly with the magnitude of negative priming for impossible objects. That is, larger amounts of positive priming for possible objects should be accompanied by larger amounts of negative priming for impossible objects.

To evaluate this issue, we analyzed data from 18 separate between-subjects experimental conditions (drawn from Schacter et al. (1990a) and Experiments 1–3 of the present paper) in which priming of possible objects has been observed. We computed the difference between studied and nonstudied possible objects (which was always positive) and the difference between studied and nonstudied impossible objects (which was sometimes positive and sometimes negative). According to the response bias argument, these two difference scores should be significantly negatively correlated: As the difference score for possible objects becomes increasingly positive, the difference score for impossible objects should become increasingly negative. However, analysis of difference scores from the 18 experimental conditions revealed essentially no correlation ($r = -.06$) between the two sets of scores. These data indicate that the presence of negative priming with impossible objects is unrelated to the magnitude of positive priming for possible objects.

The general implication of this result is that response bias should not necessarily be invoked as an explanation of priming for possible objects whenever negative priming of impossible objects is observed. Although the occasional trend for negative priming may signal the presence of some response bias, it might also reflect the nature of encoding processes elicited at the time of study. For example, if an encoding task induces subjects to attend to only certain parts of an object, which themselves may form a structurally possible subset of a globally impossible object, the resultant structural description might increase the likelihood of making a possible response on the object decision task (see Peterson & Gibson, in press, for evidence that allocating spatial attention within an object can influence the form of the structural description).

It is also tempting to speculate that the phenomenon of negative priming of impossible objects is for the most part an expression of random variability around a mean priming score of zero. Consistent with this idea, we computed the overall levels of object decision accuracy for impossible objects from the 18 experimental conditions included in the foregoing analysis. Performance was virtually identical for studied (.64) and for nonstudied (.65) objects, thus indicating zero priming of impossible objects across conditions (the corresponding proportions for possible objects in the same 18 experimental conditions were .77 for studied objects and .64 for nonstudied objects).

With respect to Experiment 3, the foregoing considerations support the argument that priming of possible objects in the left/right+ condition is at least partly attributable to encoding of a structural description—and not solely to response bias—despite the trend for negative priming of impossible objects. This conclusion makes sense in view of the fact noted earlier that the left/right and three-dimensional encoding tasks, when given alone, produce structurally based priming, thus making it difficult to understand why performing both tasks would simply produce a response bias to say possible.

However one views the response bias issue, Experiment 3 provides no support for the idea that performing two different encoding tasks yields structural representations of impossible objects that support significant priming and provides further evidence that priming of impossible objects is not observed with the modified materials and task instructions developed in Experiment 1. These observations lead us to question whether any other features of our task or materials could be responsible for the failure to observe priming of impossible objects. One conceivably relevant feature concerns the size of our target drawings. For the impossible objects used in Experiments 1–3, the mean visual angle subtended was 8.2° (when viewed from 60 cm), with a range of 6.9°–10.6°. For the possible objects used in Experiment 1, the mean visual angle was 7.7°, with a range of 6.5°–8.9°; for the possible objects used in Experiments 2 and 3 the corresponding mean was 6.0° with a range of 4.7°–6.7°. Thus, impossible objects were on average larger than possible objects in all experiments.

Although there is no strong reason to suppose that size differences among objects are responsible for the pattern of priming data, we confront the issue directly in Experiment 4 by examining performance with target drawings of equal size. To accomplish this objective, we equated possible and impossible objects with respect to a reference frame of standard size and then examined object decision and recognition performance following the left–right encoding task.

Experiment 4

Method

Subjects. A total of 40 University of Arizona undergraduates participated in the experiment in return for course credits.

Design, materials, and procedure. The main design consisted of a 2 × 2 × 2 mixed factorial, with one between-subjects variable, type of test (object decision vs. recognition), and two within-subjects variables, object type (possible vs. impossible) and item type (studied vs. nonstudied). In addition, for the object decision analysis, test order (first or second) was included as a between-subjects variable.

Target materials consisted of the same 20 possible and 20 impossible objects that were used in Experiment 3. To equate these objects for size, we constructed an 8.6-cm circular reference frame. All figures were scaled to fit within the reference frame. When viewed from 60 cm, all objects subtended a visual angle of 8.16°.

Subjects initially performed the left/right encoding task, followed by either the object decision or recognition test; immediately after completion of the recognition test, subjects in this group were given the object decision test. All aspects of instructions, counterbalancing, and procedure were exactly as described for the left/right group in Experiment 3.

Results and Discussion

Object decision. The pattern of object decision performance was quite similar to that observed in previous experiments using the left/right encoding task: There was strong evidence for priming of possible objects, little evidence for priming of impossible objects, and no systematic effect of test order (see Table 7). An ANOVA revealed significant main effects of object type, $F(1, 38) = 7.89$, $MS_e = .041$, $p < .01$, and item type, $F(1, 38) = 10.71$, $MS_e = .013$, $p < .01$. More important, there was a significant Object Type × Item Type interaction, $F(1, 38) = 14.92$, $MS_e = .009$, $p < .001$, thereby confirming that priming was observed for possible but not for impossible objects. There was also a marginally significant Test Order × Object Type × Item Type interaction, $F(1, 38) = 4.06$, $MS_e = .009$, $p = .051$, reflecting a trend for priming of impossible objects on the first test, together with a trend toward negative priming of impossible objects on the second test, whereas similar levels of priming for possible objects were observed on both tests. However, neither of the trends observed with the impossible objects approached significance (both ts < 1). Moreover, neither the main effect of test order nor any other interactions involving test order were significant (Fs < 1.51). Accordingly, the major result of Experiment 4 is that priming of possible but not of impossible objects was observed, thus indicating that previous failures to observe priming of impossible objects cannot be attributed to the variable size of target drawings because size was equated in the present experiment.

Table 7
Object Decision Performance: Experiment 4

Item type	Test order: First	Second	M
Possible objects			
Studied	.82	.79	.81
Nonstudied	.71	.67	.69
M	.77	.72	—
Impossible objects			
Studied	.71	.61	.66
Nonstudied	.65	.66	.66
M	.68	.64	—

Note. The encoding task consisted of a 5-s left/right judgment about size standardized objects.

In light of our earlier discussion of response bias and negative priming, it is perhaps worth noting that the data in Table 7 once again illustrate the independence of positive priming of possible objects and negative priming of impossible objects. In the object decision first condition, there was a +.11 priming effect for possible objects together with a +.06 effect for impossible objects; in the object decision second condition, there was a +.12 priming effect for possible objects together with a −.05 effect for impossible objects. Thus, the magnitude of priming for possible objects was virtually identical whether there was positive or negative priming of impossible objects. Nevertheless, we computed Yule's Q for studied and for nonstudied objects to determine whether significant differences were observed. The Q for studied items (+.65) was significantly higher than the Q for nonstudied items (+.51), $t(39) = 2.67$, $p < .01$.

Recognition memory. Recognition performance showed a relatively small difference between hit rates for possible objects (.70) and impossible objects (.66), together with a lower false alarm rate for the possible objects (.19) than for the impossible objects (.31). Analysis of the hit rate data alone failed to show a significant difference between the two types of objects, $t(39) < 1$, but combined analysis of hits minus false alarms did, $t(39) = 2.96$, $p < .01$.

General Discussion

Our experiments have provided new information about the properties and characteristics of implicit memory for novel visual objects, as indexed by priming effects on the object decision task, and have provided further evidence that implicit and explicit memory can be dissociated. Priming for structurally possible objects was equivalent after one or four 5-s left/right judgments (Experiment 1) and was also about the same in the left/right condition and the left/right+ condition, in which subjects performed the left/right task and a three-dimensional classification task (Experiment 3). By contrast, explicit memory was significantly higher after four repetitions than after one, and it was also higher in the left/right+ condition than in the left/right condition. Experiment 2 showed that a single 1-s left/right judgment did not produce priming on a subsequent object decision test, whereas five 1-s left/right judgments did. No evidence for priming of structurally impossible objects was observed in any experiment, despite (a) inclusion of only those objects that elicited nearly perfect intersubject agreement, (b) modification of task instructions from our previous experiments to avoid the identification of impossible responses with negative responses, (c) provision of four or five repetitions of the left/right encoding task (Experiments 1 and 2) or different structural encoding tasks (Experiment 3), and (d) use of size-standardized objects (Experiment 4).

The failure to document priming of impossible objects, despite numerous experimental variations, indicates that it is unlikely that this finding is attributable to some spurious or idiosyncratic feature of our instructions, materials, or procedures. Moreover, the absence of priming, even when explicit memory for impossible objects was quite high, indicates that attempts to explain our results in terms of a generally weak memory representation for impossible objects are unlikely to be useful. Of course, the fact that we have not found priming of impossible objects on the object decision task need not imply that such priming cannot be observed on this task under some set of experimental conditions. Our findings do indicate, however, that there is a wide range of conditions in which priming of possible objects is robust, whereas priming of impossible objects is absent.

In view of the foregoing considerations, we think that our data can be most readily interpreted in terms of our previously stated *structural description system* hypothesis (Schacter et al., 1990a): Priming on the object decision task depends on prior encoding of structural descriptions that preserve global, three-dimensional information about novel objects, and the structural description system that is involved in such priming either cannot compute, or has great difficulty computing, a global representation of an impossible object. That is, the system cannot settle in on a single global interpretation of an impossible object, precisely because there is no globally consistent interpretation of the structure of such an object. The structural description system can, however, compute a globally consistent interpretation of a possible object, and it is this representation that we assume provides a basis for priming. This hypothesis suggests that explicit memory for impossible objects—which was quite high in several experimental conditions—must be based on information other than a global structural description, such as representations of salient parts of the object.

These ideas led to a prediction concerning task conditions in which it should be possible to observe priming for impossible objects. Specifically, such priming should occur when an implicit test is used that requires access to information about individual parts of an object. If an implicit test does not require access to information about structural relations—in contrast to the demands of our object decision task—then there should be robust priming with impossible objects because such priming would be based on access to representations of possible parts rather than impossible wholes. An important task for future research is to develop appropriate implicit tests in which priming is supported by prior encoding of component parts of possible and impossible objects.

Turning to the results on priming of structurally possible objects, the pattern of data from Experiments 1–3 suggests, on the one hand, that the encoding activities entailed in making a 5-s left/right judgment (and a 5-s three-dimensional classification) produce a complete structural description of an object with respect to the demands of the object decision test: The magnitude of priming is not increased by additional repetitions of the left/right task nor by combining the left/right and three-dimensional classification tasks. On the other hand, the data indicate that a 1-s left/right judgment does not enable subjects to acquire the sort of structural information needed to support priming, thus suggesting that it takes time to carry out the sort of extensive analyses necessary to produce a global structural description.

The failure to observe priming in the 1-s encoding condition is consistent with, and helps to make sense of, our repeated failure to observe significant priming from the appearance of studied and nonstudied objects on the recognition test in the present experiments and previous ones (Schacter et al., 1990a) because subjects' recognition latencies are on the order of 1 s in our paradigm. We did observe trends toward test priming in individual conditions of particular experiments, but we also observed trends in the opposite direction (i.e., more priming when object decision was given first than when it was given second) in other experimental conditions, perhaps reflecting variability associated with a between-subjects comparison. Combined across studied and nonstudied items from the four experiments, however, overall performance for possible objects was .69 when the object decision test was given first, and .71 when the object decision test was given second; performance for impossible objects was .65 in both conditions. Clearly, there is no compelling evidence that processing an object on the recognition test produces priming. In view of the data from the 1-s encoding condition, this is probably because recognition judgments are made too quickly to permit the necessary structural analyses to be carried out. It is interesting to note in this regard that strong test priming effects have been observed on the fragment completion test (e.g., Tulving, Schacter, & Stark, 1982). Any number of differences in tasks and materials could account for the contrasting test priming data from object decision and fragment completion. However, one speculative possibility is that this pattern is produced by different characteristics of the structural description subsystem that we assume is involved in object decision priming and the word-form sub-system that appears to be involved in fragment completion priming (see Schacter, 1990).

One potential objection to our suggestion that a 5-s left/right judgment produces a complete structural description of a possible object concerns the potential role of ceiling effects in the data that are relevant to this claim. Perhaps there was no more priming after four left/right judgments than after one, or in the left/right+ task relative to the left/right task, because performance in all conditions was at or close to ceiling levels. Two points about this possibility are worth noting. First, any argument for a ceiling effect would have to invoke some sort of a functional ceiling because object decision accuracy was under 90% in all conditions. Second and more important, appeals to a functional ceiling effect are not satisfactory, either. Consider, for example, the data from Experiment 1 indicating that object decision performance for studied items did not differ following one left/right judgment (.74) and four left/right judgments (.71). An argument for ceiling effects would hold that under the present task conditions (i.e., 100-ms exposure), object decision accuracy cannot exceed approximately 75% accuracy; hence the failure to observe an effect of four exposures versus one exposure. This argument fails, however, because in other experimental conditions we have observed levels of object decision accuracy for studied items over 80% (e.g., Experiment 4 in the present paper, and Experiment 1 in Schacter et al., 1990a) and as high as 87% (see Schacter et al., 1990b). We therefore think that ceiling effects are not relevant to the pattern of data that we obtained and that the failure to increase priming with multiple exposures and tasks indicates that a 5-s left/right judgment yields all the structural information necessary to support object decision priming. Explicit memory, on the other hand, benefits from repetitions beyond a single 5-s left/right judgment, perhaps reflecting an important difference between the episodic system that we assume is involved in recognition and the structural description system that we assume is involved in object decision priming.

Consistent with these ideas, similar patterns of data have been reported with another task that taps priming of novel nonverbal information. In an experiment by Musen and Treisman (1990), subjects were given 3-s exposures to novel dot patterns and were given an additional 7 s to "rehearse" each pattern. Implicit memory was assessed with a test in which subjects attempted to copy dot patterns from a brief masked exposure. Musen and Treisman found that subjects correctly produced more studied than nonstudied patterns, thereby indicating the presence of priming. Most important with respect to the present concerns, repetitions of the studied dot patterns did not increase the magnitude of priming relative to the single-exposure condition, even though explicit memory performance was sensitive to additional repetitions. If we assume that priming in the Musen and Treisman paradigm depends on the structural description system—an assumption that is entirely consistent with the authors' data and their interpretation of it—then we have additional evidence that priming effects in this system are not increased by repeated exposures to an object or pattern.

As noted in the beginning of the article, we view the structural description system as a presemantic system—distinct from episodic memory—that is dedicated to representing information about the form and structure of objects and that does not handle semantic, functional, or associative information about them. This idea is based partly on neuropsychological studies of patients with object agnosia who demonstrate relatively intact access to structural knowledge about objects, despite severe impairments in gaining access to information about their functions or associative properties (Riddoch & Humphreys, 1987; Warrington, 1975, 1982; see Schacter, 1990, for more extensive discussion). The idea also receives support from our experiments showing that requiring subjects to relate target objects to their semantic knowledge of real-world objects either produces no priming (Experiment 2 in Schacter et al., 1990a) or no more priming that the left/right task (Experiment 3 in the present article and in Schacter et al., 1990a), even though these same manipulations greatly enhance explicit memory. This is precisely the pattern of results that would be expected if object decision priming were mediated by a presemantic system that can function independently of episodic memory.

Recent experiments have extended the finding that object priming does not require semantic study processing to another implicit task, in which we think that priming is mediated by the structural description system. Schacter and Merikle (1990) showed subjects line drawings of familiar objects and required them either to think of functions that each object performs (semantic study task) or to count the number of vertices in each object (structural study task). Priming was assessed with an object completion task in which subjects were briefly exposed to perceptual fragments of studied and nonstudied objects and were required to complete them with the first object that came to mind (for further discussion of the logic of this test, in contrast to traditional picture fragment completion tests, see Schacter, Delaney, & Merikle, 1990). Explicit memory was assessed by providing the same fragment cue and by instructing subjects to try to remember the correct object from the study list. Results indicated that explicit memory was higher after semantic encoding than after structural encoding, whereas priming was equivalent in these two conditions. Thus, priming in this paradigm did not require any semantic study processing.

This overall pattern of results, then, is consistent with the notion that a presemantic structural description system is involved in object priming on object decision, completion, and identification tasks, whereas episodic memory is responsible for explicit recall and recognition of objects. Converging evidence on this point is provided by the finding that amnesic patients show normal priming on the object decision task (Schacter, Cooper, Tharan, & Rubens, in press).Of course, it is no doubt possible to offer an account of these results that does not involve postulating distinct memory systems (e.g., Jacoby, 1983; Masson, 1989; Roediger et al., 1989). Nevertheless, our data are entirely consistent with a multiple systems account, and in addition there are a variety of heuristic and theoretical reasons for adopting such a stance (for discussion, see Hayman & Tulving, 1989b; Schacter, 1990; Schacter et al., 1990a; Squire, 1987; Tulving & Schacter, 1990).

With respect to future research, conceptualizing implicit memory for visual objects in terms of a presemantic structural description system sets the stage for studies that exploit priming effects as tools for investigating the nature of structural descriptions: Precisely what kinds of information are preserved in structural descriptions of objects? Does changing the size, the color, or the orientation of an object between study and test reduce or eliminate priming? How are structural descriptions used for purposes of object identification? We have already begun to investigate such issues with the object decision task, and others have reported similar investigations with related priming tasks (e.g., Biederman & Cooper, 1989). These investigations should provide insight into the mechanisms of implicit memory and are also likely to elucidate fundamental issues concerning the representation and identification of visual objects (cf. Biederman, 1987; Humphreys & Quinlan, 1987; Kosslyn, 1987; Marr, 1982).

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Preserved Priming of Novel Objects in Patients with Memory Disorders

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Abstract

■ Amnesic patients perform poorly on explicit memory tests that require conscious recollection of recent experiences, but frequently show preserved facilitations of performance or *priming effects* on implicit memory tasks that do not require conscious recollection. We examined implicit memory for novel visual objects on an *object decision test* in which subjects decide whether structurally possible and impossible objects could exist in three-dimensional form. Patients with organic memory disorders showed robust priming effects on this task—object decision accuracy was higher for previously studied objects than for nonstudied objects—and the magnitude of priming did not differ from matched control subjects or college students. However, patients showed impaired explicit memory for novel visual objects on a recognition test. We argue that priming is mediated by the structural description system, a subsystem of the perceptual representation system, that operates at a presemantic level and is preserved in amnesic patients. ■

Organic memory disorders can be produced by a variety of neurological conditions, including Korsakoff's syndrome, encephalitis, anoxia, ruptured aneurysms, and head injuries. Such disorders typically involve damage to hippocampus, diencephalon, or basal forebrain (cf. Butters & Stuss, 1989; Damasio, Graff-Radford, Eslinger, Damasio, & Kassell, 1985; Squire, 1987; Weiskrantz, 1985), and are characterized by an impaired ability to remember recent events and learn new information despite normal intelligence, perceptual processing, and language function (e.g., Mayes, 1988; Rozin, 1976; Squire, 1987). Because amnesic patients' memory deficits can be quite severe—interfering with their ability to remember even the most salient events of their everyday lives (e.g., Milner, Corkin, & Teuber, 1968; Schacter, 1983; Schacter, Glisky, & McGlynn, 1990)—it is tempting to conclude that such patients suffer from a global deficit that impairs all forms of memory and learning.

A major theme of recent neuropsychological research, however, is that even patients with severe memory dis-orders possess some preserved memory abilities. Specifically, despite their impaired ability to explicitly or consciously remember recent experiences and new information, amnesic patients often show intact *implicit memory* (Graf & Schacter, 1985; Schacter, 1987a, 1987b); that is, they show normal memory performance on tasks that do not require conscious, explicit recollection of recent experiences. Thus, for example, amnesic patients can acquire perceptual and motor skills normally (e.g., Cohen & Squire, 1980; Milner, Corkin, & Teuber, 1968), exhibit robust classical conditioning (Daum, Channon, & Canavan, 1989; Weiskrantz & Warrington, 1979), and show normal influences of prior experience on various cognitive judgments (Benzing & Squire, 1989; Johnson, Kim, & Risse, 1985).

Perhaps the most extensively investigated implicit memory phenomenon in patients with memory disorders is known as repetition or direct *priming*: facilitated identification of words or objects from reduced perceptual cues (Cofer, 1967; Tulving & Schacter, 1990). In a priming experiment, subjects are typically shown a list of words, pictures, or some similar stimulus materials.

followed by an implicit memory test and an explicit memory test. On the implicit memory test, subjects are required to perform a task that does not require conscious recollection of the study list, such as *stem* or *fragment completion* (i.e., completing a word stem or fragment with the first word that comes to mind), *word identification* (i.e., identifying a word from a brief perceptual exposure), or *lexical decision* (i.e., deciding whether a letter string is a real word or a nonword). Priming is inferred when performance on previously studied items is more accurate or faster than performance on new items that were not previously studied. On the explicit memory test, subjects are required to think back to the study list and either recall or recognize the target items. The striking finding from a large number of experiments, beginning with the classic work of Warrington and Weiskrantz, is that amnesic patients show normal priming effects (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985; Cermak, Blackford, O'Connor, & Bleich, 1988; Gabrieli, Milberg, Keane, & Corkin, 1990; Graf, Squire, & Mandler, 1984; Jacoby & Witherspoon, 1982; Moscovitch, 1982; Schacter, 1985; Schacter & Graf, 1986b; Shimamura & Squire, 1984; Tulving, Hayman, & Macdonald, 1991; Warrington & Weiskrantz, 1968, 1974; for review, see Schacter, 1987b; Shimamura, 1986).

Demonstrations of preserved priming in patients with impairments of explicit memory have important implications for theories of memory and amnesia, because they suggest that priming is mediated by a brain system that is distinct from, and can function independently of, the memory system that is necessary for explicit recollection of recent events. There is widespread agreement that amnesic patients suffer from impairment to an *episodic* (e.g., Kinsbourne & Wood, 1975; Schacter & Tulving, 1982; Tulving, 1972, 1983) or *declarative* (e.g., Cohen & Squire, 1980; Squire, 1987) memory system that normally supports explicit remembering and depends on the integrity of brain structures that are damaged in amnesia. By contrast, there is less agreement concerning the nature of the system or process that subserves priming (cf. Cermak et al., 1985; Cohen, 1984; Gabrieli et al., 1990; Graf et al., 1984; Moscovitch, Winocur, & McLachlan, 1986; Schacter, 1987b; Squire, 1987).

One approach to this latter issue is provided by a general framework for understanding dissociations between priming and explicit memory that we have put forward (Schacter, 1990; Schacter, Cooper, & Delaney, 1990; Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990). A central idea in this framework is that priming on implicit tests such as stem and fragment completion, word identification, or lexical decision is to a large extent a *presemantic* phenomenon. The key evidence here is that priming effects do not require semantic processing of an item at the time of study: robust priming is observed following nonsemantic study tasks, such as counting vowels and consonants in a word, that produce low levels of explicit memory (cf. Bowers & Schacter, 1990; Graf & Mandler, 1984; Graf et al., 1984; Jacoby & Dallas, 1981). However, priming does require appropriate perceptual/structural processing at both study and test: Priming effects are reduced or eliminated by changing the sensory modality of presentation between study and test (e.g., Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981; Schacter & Graf, 1989), little or no priming is observed between pictures and words (e.g., Weldon & Roediger, 1987), and under certain conditions, study/test changes in the exact surface form of an item can reduce the magnitude of priming (e.g., Graf & Ryan, 1990; Roediger & Blaxton, 1987; but see Carr, Brown, & Charalambous, 1989).

The foregoing observations suggest that priming effects on a variety of implicit tasks depend heavily on brain systems that operate on perceptual/structural information, but not on semantic/associative information. Independent evidence for the existence of such systems derives from a separate area of research on patients with reading deficits and object processing deficits. In the verbal domain, studies of patients who can read words aloud despite severely impaired comprehension of those words (e.g., Schwartz, Saffran, & Marin, 1980) suggest the existence of a presemantic *visual word form system*; in the object domain, studies of patients who show intact access to structural knowledge about familiar objects despite impaired access to knowledge of their functional and associative properties have pointed to the existence of a *structural description system* (e.g., Bauer & Rubens, 1985; Riddoch & Humphreys, 1987; Warrington, 1975, 1982).

We have suggested that the word form and structural description systems can be thought of as subsystems of a more general *perceptual representation system* (PRS) that plays a crucial role in priming (Schacter, 1990; Tulving & Schacter, 1990; see also Gabrieli, Milberg, Keane, & Corkin, 1990; Johnson, 1983). The general idea is that study of a word or an object creates a representation of its perceptual structure in PRS, thereby facilitating subsequent identification of the item from reduced perceptual cues; this facilitation of performance constitutes implicit memory for the item. Explicit memory for a studied word or object requires an additional episodic/declarative memory system that permits semantic elaborations about an item as well as associations between an item and its context (i.e., place/time information). By this view, the well-established finding that amnesic patients show intact priming of familiar words despite poor explicit memory can be attributed to a normally functioning visual word form subsystem. In view of evidence from neuroimaging studies that the word form system has an extrastriate occipital locus (Petersen, Fox, Posner, Mintun, & Raichle, 1988) and the fact that this cortical region is typically spared in patients with memory disorders, the priming data make neurobiological as well as psychological sense.

In the PRS framework, priming of nonverbal information is thought to depend on the structural description subsystem. Although studies of college students have provided data that are consistent with this notion (cf. Kersteen-Tucker, 1991; Kroll & Potter, 1984; Musen & Treisman, 1990; Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991), there is little evidence from experiments with memory-impaired patients that directly supports the idea (for review, see Schacter, Delaney, & Merikle, 1990). Several studies have shown that exposure to line drawings of common objects facilitates amnesic patients' ability to identify fragmented pictures of the objects (Milner et al., 1968; Warrington & Weiskrantz, 1968). In these studies, however, amnesics showed less priming than did control subjects, perhaps because controls made use of explicit memory strategies not available to amnesic patients. Various other paradigms have also yielded evidence for priming of familiar objects (cf. Baddeley, 1982; Crovitz, Harvey, & McClanahan, 1981; Meudell & Mayes, 1981) and unfamiliar patterns (Cohen, Abrams, Harley, Tabor, Gordon, & Sejnowski, 1986) in amnesic patients, but it is not clear from these experiments whether priming is intact relative to controls. However, a recent study by Gabrieli et al. (1990) demonstrated intact priming of novel dot patterns in the severely amnesic patient H.M.

Although it thus seems clear that amnesic patients show some priming of nonverbal information, there is little evidence that such priming is normal, and none of the paradigms that have been used was designed with a view toward assessing the possible role of the structural description system. The purpose of the present study is to investigate priming of nonverbal information in a group of patients with organic memory disorders, using an experimental paradigm in which there are empirical grounds to argue that the observed priming effects depend on the structural description system.

The paradigm that we used has been developed and explored in experiments with college students (Schacter, Cooper, & Delaney, 1990; Schacter et al., 1991a), and involves presentation and testing of line drawings such as those depicted in Figure 1. All of the line drawings depict novel, unfamiliar objects that do not actually exist in the three-dimensional world. Half of the objects are structurally *possible*—their surfaces and edges are connected such that they *could* exist in three-dimensional form, whereas the other half are structurally *impossible* objects—they contain ambiguous lines and planes that create impossible relations that would prevent them from existing in three-dimensional form.

To assess priming or implicit memory for these objects, we developed an *object decision task* in which previously studied drawings and nonstudied drawings are briefly presented, and subjects decide whether each drawing is structurally possible or impossible; no reference is made to the prior study episode. We argued that making the possible/impossible decision requires access to information about the global, three-dimensional structure of each object. Accordingly, we reasoned that encoding of information about global object structure during a study episode should improve the accuracy of subsequent object decision performance, and that this priming effect would constitute evidence of implicit memory for novel visual objects.

Our experiments using this task have provided several lines of evidence that are consistent with these ideas. The most important findings for the present purposes are that (1) priming is observed on the object decision test following study tasks that involve encoding of global, three-dimensional structure (e.g., judging whether the object faces primarily to the left or right), but not following study tasks that involve encoding of local, two-dimensional features (e.g., judging whether the object contains more horizontal or vertical lines), (2) semantic or elaborative encoding tasks, such as generating verbal labels for the objects, yield much higher levels of explicit memory performance on a recognition test than do structural encoding tasks, but do not increase—and sometimes reduce—the magnitude of priming on the object decision test, (3) priming exhibits stochastic indepedence (Hayman & Tulving, 1989) from recognition memory, and (4) priming is consistently observed for structurally possible objects, but not for structurally impossible objects.

The fact that priming effects on the object decision test require prior structural encoding, but not semantic encoding, supports the idea that priming is based on a presemantic structural description system; the fact that priming can be dissociated from explicit recognition performance suggests that this system can operate independently of episodic/declarative memory. Within the context of these ideas, the failure to consistently observe priming for structurally impossible objects may indicate that it is difficult to compute a global structural description of an impossible object.

In view of these findings with normal subjects, the performance of patients with explicit memory deficits in the object decision paradigm should be informative. If the structural description system is spared in these patients, and can thus establish global representations of novel objects, then they should show normal priming effects, with greater priming for possible than impossible objects. If such priming is not observed, however, our ideas about the nature of the structural description system and its relation to episodic/declarative memory would have to be revised.

To address these issues, we examined implicit and explicit memory for novel objects in six patients with organic memory disorders, six matched control subjects, and six student controls. All subjects initially performed a structural encoding task (judging whether each object faces primarily to the left or to the right). They then made possible/impossible object decisions about studied and nonstudied objects, and were subsequently given an explicit recognition test for all objects.

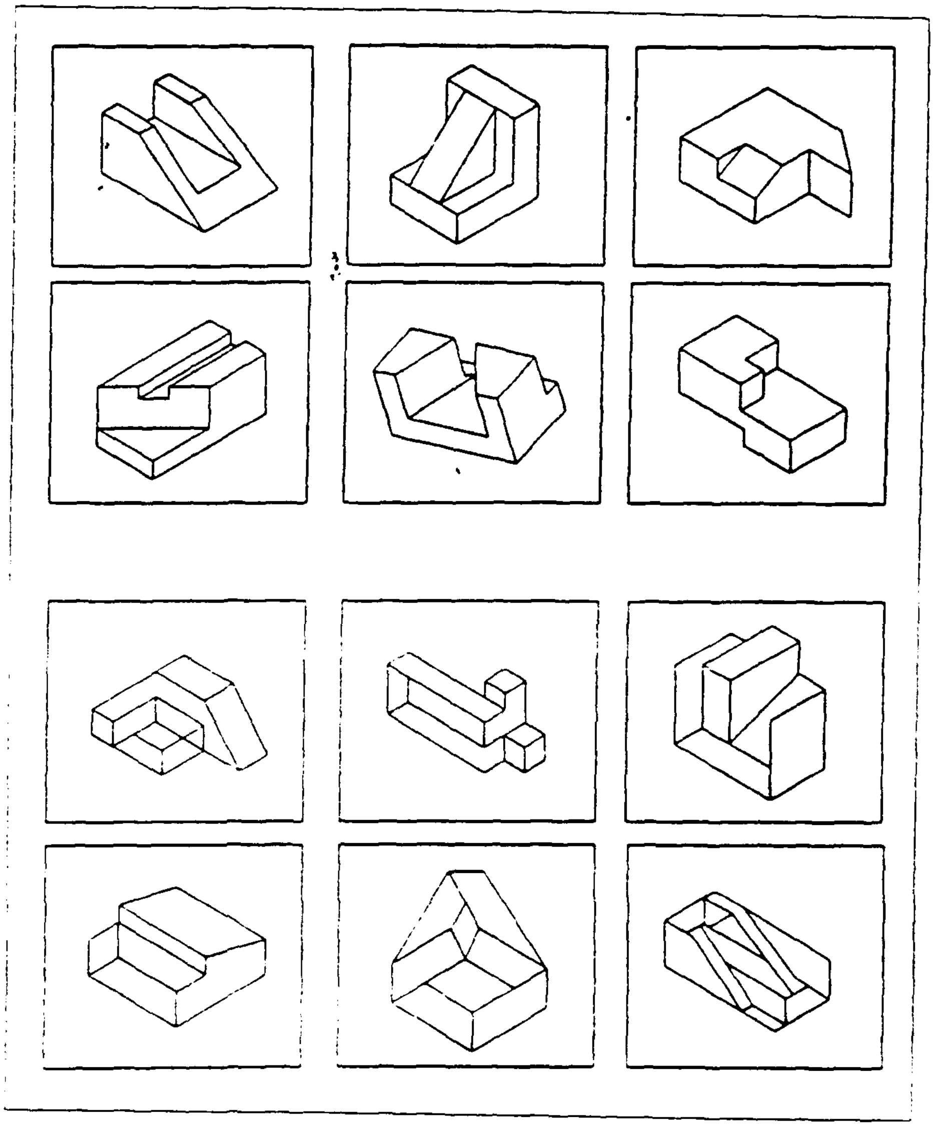

Figure 1. Representative examples of target objects that were used in the experiment. The figures in the upper two rows depict structurally possible objects that could exist in three-dimensional form. Figures in the lower two rows depict structurally impossible objects that could not exist in three-dimensional form.

RESULTS

Object Decision

Table 1 displays the proportions of correct object decisions made about studied and nonstudied possible and impossible objects by the three subject groups. Overall baseline performance for nonstudied objects was close to .50 for each group. However, patients with memory disorders, and matched control subjects to a lesser degree, tended to use the "possible" response more often than the "impossible" response for nonstudied items, whereas college students showed a nearly equal distribution of "possible" and "impossible" responses. In view of the small number of subjects per condition ($n = 6$), these unanticipated fluctuations in the relative frequency of "possible" and "impossible" responses for nonstudied items are difficult to interpret.

The critical finding displayed in Table 1 is that the amnesic patients' performance on the object decision test was more accurate for studied objects (.61) than for nonstudied objects (.51). Moreover, the magnitude of the priming effect, as indicated by subtracting the proportion correct for nonstudied objects from the proportion correct for studied objects, was virtually identical in patients (.10), matched controls (.11), and student controls (.11). Just like normal subjects in many previous experiments, patients with memory disorders showed a large priming effect for possible objects and no priming for impossible objects. Five of the six patients showed some priming for possible objects: only the head-injured patient W.C. failed to show any evidence of priming. The student control group exhibited a nearly identical pattern of results. By contrast, the matched control group showed priming for both possible and impossible objects, with

Table 1. Object Decision Performance for Studied and Nonstudied Objects by Three Subject Groups

	Subject Group/Item Type							
	Amnesic Patients		*Matched Controls*		*Student Controls*		*M*	
Object Type	*S*	*NS*	*S*	*NS*	*S*	*NS*	*S*	*NS*
Possible	.83	.63	.57	.48	.70	.48	.70	.53
Impossible	.38	.38	.55	.42	.48	.48	.47	.43
M	.61	.51	.56	.45	.59	.48	.59	.48

Note. Each entry indicates the proportion of correct object decisions in a particular condition. "S" refers to studied objects and "NS" refers to nonstudied objects.

Table 2. Recognition Performance for Studied and Nonstudied Objects by Three Subject Groups

	Subject Group/Item Type							
	Amnesic Patients		*Matched Controls*		*Student Controls*		*M*	
Object Type	*S*	*NS*	*S*	*NS*	*S*	*NS*	*S*	*NS*
Possible	.65	.32	.70	.30	.92	.25	.76	.29
Impossible	.42	.37	.69	.38	.78	.20	.63	.32
M	.54	.35	.70	.34	.85	.23	.70	.31

Note. Each entry reflects the proportion of objects called "old" in a particular experimental condition. "S" refers to studied objects and the corresponding proportions are *hit rates*. "NS" refers to nonstudied objects, and the corresponding proportions are *false alarm* rates.

a trend toward greater priming of impossible objects. However, closer inspection of the matched controls' data revealed that the apparent priming of impossible objects is almost entirely attributable to a single subject, thus suggesting that the trend is probably an artifact of small sample size.

Analysis of variance provides statistical confirmation of the foregoing description of the results. There was a main effect of Item Type (Studied vs. Nonstudied), $F(1,15) = 5.40$, MSe $= .006$, $p < .03$, confirming that significant priming was observed across groups. Importantly, there was a nonsignificant main effect of Subject Group, $F(2,15) < 1$, MSe $= .049$, and a nonsignificant Item Type × Subject Group interaction, $F(1,15) < 1$, MSe $= .006$, indicating that the overall magnitude of priming did not differ across the three groups. A significant main effect of Object Type was observed, $F(1,15) = 13.14$, MSe $= .006$, $p < .01$, showing a higher overall proportion of possible responses than impossible responses. There was also a significant Item Type × Object Type interaction, $F(91,15) = 11.97$, MSe $= .006$, $p < .01$, indicating more priming of possible than impossible objects across subject groups. However, these findings were qualified by a significant Subject Group × Item Type × Object Type interaction, $F(2,15) = 5.86$, $p < .02$. The interaction reflects the fact that patients and student controls showed priming for possible but not impossible objects, whereas matched controls show a trend for more priming of impossible than possible objects.

Recognition memory

Data from the yes/no recognition test are displayed as hits (i.e., "yes" responses to studied objects) and false alarms (i.e., "yes" responses to nonstudied objects) for each subject group (Table 2). To correct for possible criterion differences across groups, recognition accuracy was assessed with a corrected recognition measure (hits minus false alarms). These data contrast with the object decision results, inasmuch as they show a strong effect of subject group. Recognition accuracy was lower in amnesic patients (.19) than in matched controls (.36) or in student controls (.63). Recognition was more accurate for possible than impossible objects in each subject group.

An analysis of variance on the corrected recognition scores revealed significant main effects of Subject Group, $F(2,15) = 13.11$, MSe $= .044$, $p < .001$, and Object Type, $F(2,15) = 11.57$, MSe $= .017$, $p < .005$, and a nonsignificant Subject Group × Object Type interaction, $F(2,15) = 2.29$, MSe $= .017$. Planned comparisons showed significantly lower levels of recognition accuracy in the patient group than in either matched controls, $t(10) = 1.85$, $p < .05$ or student controls, $t(10) = 5.17$, $p < .001$, and

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significantly lower levels of recognition accuracy in matched controls than in student controls, $t(10) = 3.26$, $p < .01$

Relation Between Object Decision and Recognition

The foregoing results indicate that patients with memory disorders showed intact priming on the object decision test despite impaired recognition. To assess the relation between object decision and recognition performance more directly, we performed a combined ANOVA in which Type of Test was a within-subjects factor. For each subject, we entered a priming score (proportion correct for studied objects minus proportion correct for nonstudied objects) and a corrected recognition score (hits minus false alarms). The critical outcome of this combined ANOVA was a significant Subject Group × Type of Test interaction, $F(2,15) = 6.75$, $MSe = .041$, $p < .01$. The interaction is depicted graphically in Figure 2.

To examine further the relation between object decision and recognition performance, we performed contingency analyses that allow us to determine whether priming on the object decision task is dependent on, or independent of, recognition memory. In previous studies with college students, we have found that object decision priming exhibits stochastic independence from recognition performance (Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delany, Peterson, & Tharan, 1991)—that is, the magnitude of the priming effect is uncorrelated with recognition performance. To assess independence, we used the Yule's Q statistic, a special case of Goodman & Kruskal's (1954) gamma correlation that applies to the analysis of data from 2 × 2 contingency tables. Q is a measure of the strength of relation between two variables that can vary from +1 (positive association) to −1 (negative association), where 0 reflects complete independence (see Hayman & Tulving, 1989, for more detailed discussion). Our contingency analysis included only possible objects, because priming of possible objects was observed in all subject groups. For each of the three groups, we constructed 2 × 2 contingency tables for studied possible objects in which each of the four cells corresponded to one of the four joint outcomes of the object decision and recognition tasks: (1) correct response on both object decision and recognition, (2) incorrect responses on both object decision and recognition, (3) correct response on object decision and incorrect response on recognition, and (4) correct response on recognition and incorrect response on object decision. The Q analysis was performed on each contingency table according to the procedure suggested by Hayman and Tulving (1989). The resulting Q values were −.099 for amnesic patients, −.119 for matched controls, and +.262 for student controls. None of the Q values differed significantly from zero (all $\chi^2 < 1$), thereby indicating that object decision priming and recognition memory were independent in each of the three subject groups. Although there was a trend for some positive association in student controls and slight negative association in patients and in matched controls, the Q value for the student controls group did not differ significantly from the Q value for either of the other groups (both $\chi^2 < 1$).

It is also perhaps worth noting that we observed independence under conditions in which the implicit

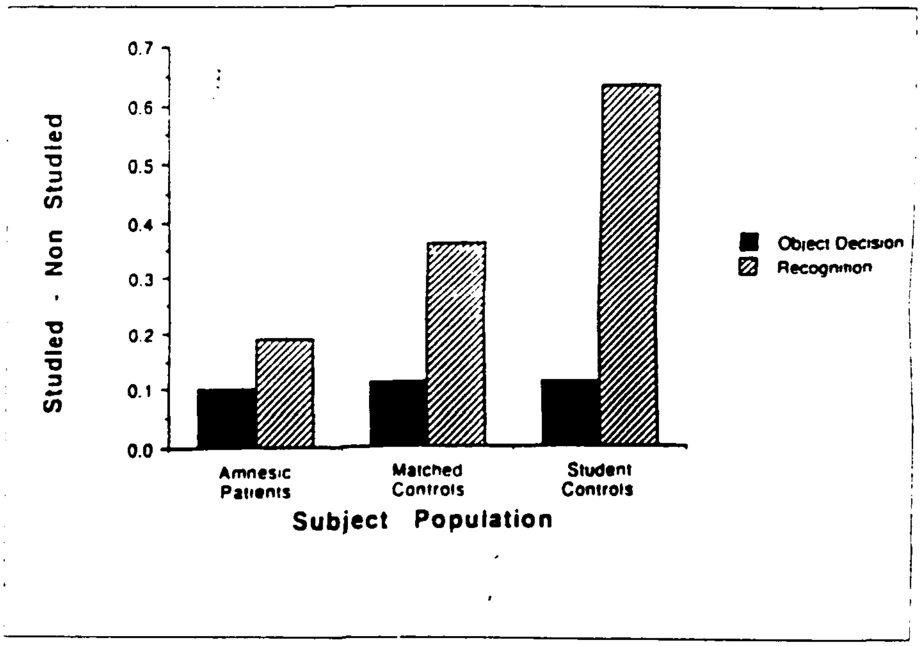

Figure 2. Object decision and recognition performance for the three subject groups. Priming scores and corrected recognition scores are depicted on the y axis. Priming scores were computed by subtracting the proportion of correct object decisions for nonstudied items from the proportion of correct object decisions for studied items. Corrected recognition scores were computed by subtracting the proportion of "yes" responses to nonstudied items (false alarms) from the proportion of "yes" responses to studied items (hits). Priming scores remained constant across the three groups, whereas corrected recognition scores increased substantially, as indicated by a significant interaction between subject group and type of test.

Table 3. Characteristics of Individual Amnesic Patients

Patient	Sex	Etiology	Age (years)	Education (years)	WMS-R				Recognition	
					IQ	GM	ATN	DR	WD	FC
D.H.	F	Aneurysm	60	13	100	76	89	62	42	43
H.B.	M	Aneurysm	55	12	103	93	109	62	44	30
J.W.	M	Aneurysm	29	13	88	57	68	<50	28	43
W.C.	M	Head injury	45	15	104	86	111	58	40	40
K.K.	F	Head injury	34	14	99	72	107	67	44	39
F.K.	[illegible]	Uncertain	74	12	104	52	100	54	32	30

Note. IQ scores are full-scale IQs from the Wechsler Adult Intelligence Scale-Revised (WAIS-R). WMS-R is the Wechsler Memory Scale-Revised; scores for indices of general memory (GM), attention (ATN), and delayed recall (DR) are presented separately. The WMS-R does not provide scores below 50. In the normal population, each WMS-R index and the WAIS-R produce a mean of 100 and standard deviation of 15. Recognition memory was assessed with the Warrington Recognition Test, which is a test of immediate, two-alternative forced-choice recognition for 50 words (WD) and 50 faces (FC). Maximum number correct is 50, and chance performance is 25. Patients achieved significantly lower scores than matched controls on GM and DR from the WMS-R, and on the Warrington Recognitoin Test, but did not differ significantly from controls on age, education, or IQ (see text).

memory task (object decision) preceded the explicit memory task (recognition); in our previous experiments, as well as in most other studies that have assessed stochastic independence (see Hayman & Tulving, 1989; Shimamura, 1985), the explicit memory task preceded the implicit memory task. Dependence between priming and explicit memory has been observed in studies in which an implicit memory task (fragment completion) preceded a recognition task (Tulving, Schacter, & Stark, 1982), but this finding was likely attributable to the fact that subjects received an extra exposure to correctly completed items on the fragment completion task. In the object decision task, however, all items received the same test exposure.

DISCUSSION

The major finding of the present experiment is that structural encoding of novel visual objects produced a normal facilitation in the accuracy of object decision performance by patients with amnesic disorders. Intact priming was observed despite impaired performance on an explicit recognition test, and the priming effect showed stochastic independence from recognition memory. The independence of priming and explicit memory is also [illegible] by the observation that whereas explicit memory performance differed markedly across the three subject groups, the magnitude of the priming effect remained constant (Figure 2).

This pattern of results provides empirical support for the idea that implicit memory for novel visual objects, as indexed by priming on the object decision task, is mediated by the structural description system, a subsystem of PRS that is spared in amnesic patients. Explicit memory for the same objects, by contrast, appears to depend on an episodic declarative memory system that is damaged in these patients. There is considerable evidence that this latter system can be disrupted by damage to hippocampus, diencephalon, or basal forebrain (cf. Butters & Stuss, 1989; Damasio et al., 1985; Squire, 1987; Weiskrantz, 1985). It is thus tempting to suggest that the acquisition of novel structural descriptions of unfamiliar objects does not depend on the integrity of these brain structures, but this suggestion must be interpreted cautiously because we do not have direct evidence concerning the status of hippocampal or diencephalic structures in our patients. However, three of our patients did have CT-documented damage to basal forebrain (see subjects section), and these patients showed a normal pattern of priming. An important task for future studies will be to investigate object decision priming in patients with well-documented damage to hippocampus or diencephalon.

It will also be important to determine whether normal priming of novel visual objects is observed in patients with the most severe forms of amnesia. Although our patients clearly have significant memory deficits (Table 3), as a group they performed at above-chance levels on the yes/no recognition test for novel objects (Table 2) and on forced-choice recognition tests for words and faces (Table 3). Recognition memory is partially preserved in many patients with memory disorders (e.g., Hirst et al., 1986), but does not exceed chance levels in the most severe cases of amnesia (cf. McAndrews et al., 1987; Tulving et al., 1991; Warrington & Weiskrantz, 1974). We cannot yet say whether object decision priming is preserved in severe amnesia, when patients' recognition performance is at or close to chance. It is worth noting, however, that Gabrieli et al. (1990) observed intact priming of novel patterns in the severely amnesic patient H.M. despite near chance levels of recognition performance. This finding suggests that priming of novel nonverbal information can occur in the absence of explicit memory and is consistent with the idea that the structural description system plays a major role in priming of novel visual objects.

Assuming that all or most of the priming effect is attributable to the structural description system, it is important to understand the functional properties and neuroanatomical basis of this system. Consider first studies that provide information concerning the functional properties of the structural description system. As noted in the introduction, neuropsychological investigations demonstrating dissociations between preserved structural processing and impaired semantic processing in patients with various types of object recognition deficits (Riddoch & Humphreys, 1987; Warrington, 1975, 1982; Warrington & Taylor, 1978) suggest that the structural description system operates at a presemantic level; that is, the system is not involved in processing information about an object's associative or functional properties. Our studies of object decision priming in normal subjects have provided evidence consistent with this characterization: Semantic encoding tasks, which yielded higher levels of explicit memory performance than did the left/right structural encoding task, either failed to produce a corresponding increase in priming or did not yield any priming at all (Schacter, Cooper, & Delaney, 1990). We have observed similar patterns of results with encoding tasks that require subjects to think about functions that a novel object might perform (Schacter, Cooper, & Tharan, 1991).

We have also carried out experiments that allow us to begin to characterize the nature of the structural description that is involved in object decision priming (Cooper, Schacter, Ballesteros, & Moore, 1990). In one study, we manipulated the *size* of target objects between the study phase and the object decision or recognition tests. Object size remained constant from study to test in one condition and was changed in the other condition. We found that the magnitude of the priming effect on object decision performance was entirely unaffected by the size manipulation—priming was just as large in same size and different size conditions—even though recognition memory was less accurate in the different size condition than in the same size condition. This finding suggests that the representation that supports object decision priming does not include size information—an idea consistent with prior suggestions that structural descriptions of objects code only relations among component parts (e.g., Humphreys & Quinlan, 1987). Along the same lines, we also found that priming was not reduced significantly by study/test changes in the left/right orientation of target objects: Priming remained substantial when mirror image reflections of studied objects were presented on the object decision task relative to when the same objects were presented, whereas recognition was significantly lower in the mirror image condition than in the same object condition (for similar priming results with a different paradigm, see Biederman & Cooper, 1989). As noted earlier, however, object decision priming was not observed when subjects performed study tasks that involve encoding information about the local parts of an object; priming was only observed following study tasks that focus on global object structure (Schacter, Cooper, & Delaney, 1990).

The foregoing observations indicate that the structural description that underlies object decision priming is an abstract, rather than literal, representation that preserves global structural information and remains invariant over changes in size and reflection. We assume that object decision priming would exhibit these same properties in amnesic patients, and we plan to test this assumption in future studies. If the assumption is correct, then our data suggest that amnesic patients can establish size and reflection invariant structural descriptions of novel objects that preserve information about global stucture.

Whereas our experimental data allow us to develop a preliminary sketch of the properties of the system that underlie object decision priming, we have no direct evidence concerning the neuroanatomical basis of this system. Nevertheless, the functional properties that we have delineated provide suggestive clues concerning the brain stuctures that may be involved. As pointed out by Plaut and Farah (1990) in a recent review, evidence from both human and animal studies indicates that regions of inferior temporal cortex play a major role in representation of visual objects. Moreover, many of the properties of these object representations are quite compatible with the properties of object priming noted earlier: Inferior temporal regions appear to be involved in representing global aspects of object structure independently of the retinal size of the object or its left/right orientation (Plaut & Farah, 1990). Thus, object decision priming may reflect, at least in part, the establishment of a novel structural description of an object in the inferior temporal region. Consistent with this suggestion, neither our patients nor amnesic patients in general exhibit object processing deficits of the kind associated with inferior temporal damage. Indeed, magnetic resonance imaging (MRI) evidence indicates that the measured area of the temporal lobes does not differ in amnesic patients and control subjects, whereas the area of the hippocampal formation is markedly reduced in amnesics (Press, Amaral, & Squire, 1989), and temporal neocortex is reported to have been spared in patient H.M. (e.g., Gabrieli et al., 1990; Scoville et al., 1953). Accordingly, it seems plausible to suggest that inferior temporal regions could be involved in priming of novel visual objects in amnesic patients. In addition, priming of visual objects may also involve areas of extrastriate occipital cortex and parietal cortex (cf. Gabrieli et al., 1990; Schacter, 1990; Schacter, Rapscak, et al., 1990; Warrington, 1982).

Whatever the exact nature of the structural description system that supports object decision priming, our results more clearly that patients with explicit memory deficits can show intact priming for novel information that does not have a preexisting memory representation. Although it is widely accepted that amnesic patients show intact priming for familiar items that have preexisting memory representations (e.g., familiar words), evidence for priming of novel information is mixed. For example, evidence for priming of nonwords (e.g., *flig*) in amnesic patients was either absent or reduced in studies with Korsakoff patients (Cermak et al., 1985; Smith & Oscar-Berman, 1990). However, these patients typically have cognitive deficits that are not observed in other amnesic patients (cf. Mayes, 1988; Squire, 1987). Stronger evidence for priming of nonwords on a perceptual identification task has been observed in two non-Korsakoff patients with severe amnesia, H.M. (Gabrieli & Keane, 1988) and the encephalitic patient S.S. (Cermak, Blackford, O'Connor, & Bleich, 1988; see also Gordon, 1988 for a rather more complex pattern of results). In addition, there is evidence for intact priming of nonwords in amnesic patients when a measure of reading speed is used as an implicit memory task (Musen & Squire, 1990).

Priming of novel information has also been examined in studies that have used a paradigm developed by Graf and Schacter (1985) to examine whether amnesic patients show priming of new associations on a stem completion task after studying a list of unrelated paired associates (e.g., *window–reason*). On the one hand, several experiments have shown intact priming of new associations in patients with relatively mild memory disorders (Graf & Schacter, 1985; Mutter, Howard, Howard, & Wiggs, 1990; Schacter & Graf, 1986b) and in at least one severely amnesic patient (Cermak, Blackford, O'Connor, & Bleich, 1988). On the other hand, a number of experiments have reported reduced or absent priming of new associations in severely amnesic patients (Cermak, Bleich, & Blackford, 1988; Schacter & Graf, 1986b; Shimamura & Squire, 1989). Investigators who have assessed priming of new associations with other implicit memory paradigms have reported both positive findings (Moscovitch et al., 1986) and negative findings (Tulving et al., 1991). Finally, an experiment that assessed priming of novel information with a paradigm involving interpretation of ambiguous sentences reported evidence for some, but not normal, priming in patients with severe memory disorders (McAndrews et al., 1987).

We cannot yet specify reasons why the evidence for intact priming of novel information is mixed in the foregoing studies, which used verbal materials, yet is robust in the present experiment and in the study by Gabrieli et al. (1990), which used nonverbal materials. Although it is possible that the verbal/nonverbal nature of the target items played some role, additional differences in study tasks, type of target materials, test requirements, and patient populations make it difficult to draw firm conclusions regarding this issue. In addition, the paradigms that are used to study priming of new associations often involve some degree of semantic processing, whereas the paradigms that are used to assess priming of novel nonverbal information appear to rely almost entirely on perceptual/structural processing. Thus, for example, it has been shown that priming of new associations in the Graf and Schacter paradigm requires some degree of semantic study processing (Graf & Schacter, 1985; Schacter & Graf, 1986a), and that the ambiguous sentences paradigm used by McAndrews et al. (1987) relies heavily on semantic interpretive processes (Auble & Franks, 1979). By contrast, there is evidence that semantic processing is not required for object decision priming (Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, & Tharan, 1991) or priming of novel dot patterns (Musen, 1990).

In view of the foregoing considerations, we suggest that priming of novel verbal information is sometimes impaired in patients with memory disorders because such priming may require the acquisition of semantic/associative information and hence involves processes outside of PRS; priming of novel nonverbal information, at least as assessed by object decision and dot completion tasks, does not appear to involve processes outside of PRS. It is possible that the acquisition of novel semantic information depends on some of the same processes and structures that are involved in the acquisition of novel episodic information—processes and structures that are typically damaged in patients with memory disorders (cf. Gabrieli, Cohen, & Corkin, 1988; Schacter, 1987a; Squire, 1987; Tulving et al., 1991). These ideas are somewhat speculative and do not account for all pertinent observations, but they are generally consistent with the experimental facts and can be tested in future research.

Finally, we should note that our account, which depends crucially on the postulation of multiple memory systems, represents just one approach to the patterns of data that we have observed. A number of investigators have argued that dissociations between priming and explicit memory can be explained without postulating different memory systems (cf. Jacoby, 1983; Roediger, 1990; Moscovitch et al., 1986; Roediger & Blaxton, 1987). Although such approaches can accommodate many results that have been observed in studies with normal subjects, they have not provided compelling accounts of preserved priming effects in amnesia (e.g., Schacter, 1987b, 1990; Hayman & Tulving, 1989; Tulving et al., 1991). It is not clear just how a unitary memory system theory would explain preserved priming of novel objects in amnesic patients, but no doubt some sort of explanation could be formulated. The important point to stress is that our view provides a straightforward account of relevant findings with amnesic patients, fits well with the data concerning the characteristics of object decision priming in normal subjects (Cooper et al., 1990; Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991a), and receives support from semantic/structural dissociations that have been observed in patients with object recognition deficits (Bauer & Rubens, 1985; Humphreys & Riddoch, 1987; Warrington, 1975, 1982). The availability of such converging evidence from independent lines of research suggests that theorizing in terms of multiple memory systems represents a useful approach to understanding dissociations between implicit and explicit memory.

METHOD

Subjects

Six patients, three males and three females, participated in the experiment. Three patients developed memory disorders as a result of ruptured aneurysms. Patient D.H., a 60-year-old female, and patient H.B., a 55-year-old male, each suffered ruptured aneurysms of the anterior communicating artery in 1988. CT scans revealed that D.H. had sustained damage to basal forebrain and left mesial orbitofrontal lobe, while H.B. sustained damage to basal forebrain, right mesial orbiofrontal cortex, as well as infarction at the head of the right caudate nucleus. Patient J.W., a 29-year-old male, experienced ruptured aneurysm of the anterior communicating artery in 1980. CT scan showed damage to the basal forebrain and in addition showed left mesial frontal infarction in the distribution of the anterior cerebral artery. Patient W.C., a 45-year-old male, had suffered a closed head injury in 1983 and an epileptic seizure in 1988. An MRI scan was performed on this patient in 1988 and revealed significant damage to the left frontal lobe and left temporal lobe. Patient K.K. is a 34-year-old female who received a severe closed head injury in a motor vehicle accident in 1976 and remained comatose for 10 weeks. Patient F.K. is a 74-year-old female who was referred to the Memory Disorders Clinic at the University of Arizona Health Sciences Center because her husband had observed a rather sudden and marked deterioration of memory abilities about 6 weeks earlier. The results of a thorough neuropsychological evaluation were not consistent with a diagnosis of primary degenerative dementia, but did not yield a certain diagnosis.

The patients' mean age was 50 years and they had on average 13 years of education. Their overall level of intellectual function was in the normal range, as indicated by a mean IQ of 100 on the Wechsler Adult Intelligence Scale-Revised. Mean scores on the Wechsler Memory Scale-Revised (WMS-R) revealed performance levels well below the mean of 100 observed in the normal population on indices of general memory (73), including the separate indices of visual memory (82) and verbal memory (75) that combine to form the general memory index, and delayed recall (59). Performance on the attention index (97) was within normal limits. Patients also performed poorly on the Warrington Recognition memory test, recognizing on average 38/50 previously studied words and 38/50 previously studied faces on an immediate test. Data concerning the main characteristics of individual patients are presented in Table 3.

The matched control group consisted of five females and one male. t tests indicated that these subjects did not differ significantly from patients with respect to mean age (51 years), educational level (14 years), or WAIS-R IQ (108). Control subjects showed much higher levels of performance than patients on the general memory (121), verbal memory (114), visual memory (128), and delayed recall (117) indices of the WMS-R (all $ts[10] > 5.09$, $p < .001$); controls also scored higher (115) than did patients on the attention index, $t = 1.94$, $p < .05$. In addition, control subjects scored significantly higher than patients on the Warrington Recognition Test ($t = 3.97$, $p < .01$), recognizing on average 49/50 words and 45/50 faces.

In addition to the patient group and the matched controls, six University of Arizona undergraduates (three males and three females) took part in the main experiment. Patients and controls subjects were paid $10.00 for their participation; college students participated in exchange for course credits.

Materials

The critical materials were 20 possible and 20 impossible objects that have been used and described by Schacter, Cooper, Delaney, Peterson, & Tharan (1991); representative objects are shown in Figure 1. The objects were selected by Schacter et al. on the basis of two criteria: (1) when subjects were given unlimited time to decide whether objects are possible or impossible, there was near perfect agreement about the possible/impossible nature of each object (mean percent agreement across 20 subjects was 99% for both possible and impossible objects); (2) when subjects were given brief (i.e., 100 msec) exposures to each object, object decision accuracy was low (about 55–60% correct for possible and impossible objects), thereby allowing room for priming to be observed.

The materials were divided randomly into two sets, A and B, that each contains 10 possible and 10 impossible objects. Each subject studied either Set A or Set B and was subsequently tested on both sets. The objects were presented for study and test by a Compaq 386 Deskpro computer on the screen of a 12 inch Princeton Ultrasync Monitor; they subtended a mean visual angle of 8° when viewed from 60 cm. Drawings of objects were presented in medium resolution and appeared white against a uniform dark gray background.

Design and Procedure

The main experiment consisted of four variables: Subject Group (amnesic patients, matched controls, and student controls), Item Type (studied vs. nonstudied), Object decision vs recognition) The experiment was completely counterbalanced such that objects from Set A and Set B appeared equally often as studied and nonstudied objects for each of the three subject groups.

For each subject, the experimental session consisted of a sequence of three main phases: left/right encoding task, object decision test, and yes/no recognition test. For the left/right encoding task, each object was exposed for 5 sec on the computer monitor, preceded by a fixation point. Subjects were instructed that a series of drawings would be shown on the computer screen and that their task was to determine whether each object appeared to be facing primarily to the left or to the right. They were told that the drawings are not as simple as they might appear, so that they should use the full 5 sec to inspect each object carefully. The task began with presentation of five practice items, followed by presentation of the 10 possible and 10 impossible target items in random order. The target items were then presented again for 5 sec each and subjects made left/right judgments in the same manner. A previous experiment has shown that the number of study list repetitions does not affect the magnitude of priming on the object decision task (Schacter, Cooper, Delaney, Peterson, & Tharan, 1991, Experiment 1).

Subjects were then given the object decision test. In previous studies with college students, a 100 msec exposure rate has been used. However, pilot studies with elderly subjects indicated that baseline performance on the object decision task is lower in old subjects than in young subjects when both are tested with 100 msec exposures. Since both the patient group and the matched controls were older than the student controls in this experiment, we used different exposure rates in an attempt to equate baseline levels of object decision performance: 250 msec for patients and matched controls, and 50 msec for student controls. Presentation of each object was immediately followed by a darkened screen. The data in Table 1 indicate that we were largely successful in matching overall levels of baseline performance.

Subjects were instructed that they would be exposed to a series of drawings that would be flashed very quickly, and that they would decide whether each figure could actually exist in the real world. They were informed that some drawings represent valid, possible three-dimensional objects that could exist in the real world whereas others represent impossible figures that could not exist as three-dimensional objects in the real world, and that their task was to decide whether each figure is possible or impossible. Several examples of possible and impossible objects (none from the target set) were then shown to subjects. They were instructed that all possible objects must have volume and be solid, that every plane on the drawing represents a surface of the object, that all surfaces can face in only one direction, and that every line on the drawing necessarily represents an edge on the

explained the impossibilities in example objects to the subjects and answered questions as needed.

Matched controls and student controls responded with a PC mouse that they controlled with their right hand: they were told to press the left key when they thought that an object was possible and the right key when they thought that an object was impossible. Patients responded verbally in order to eliminate the possibility that they would forget which key to press. Administration of instructions took about 2 min, and subjects were reminded of task instructions thoughout test performance.

Ten practice items, five that had appeared on the study list and five that had not, were then presented at the appropriate exposure rate for each group. These drawings were followed in an uninterrupted sequence by the 20 studied and 20 nonstudied critical items, presented in a randomly determined order. Exposure of each test item was preceded by the appearance of a fixation point in the middle of the monitor. Amnesic patients told the experimenter "ready" when they were looking at the fixation point and the experimenter pressed the appropriate button to initiate the trial; matched controls and student controls initiated the trial by pressing the center button on the mouse.

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Immediately following the conclusion of the object decision task, subjects were instructed for the recognition task. They were told that they would be shown a further series of drawings, some of which had been presented when they made left/right judgments and some of which had not been presented during the left/right task. Subjects were told to make a "yes" response when they remembered seeing a drawing during the left/right task and to make a "no" response when they did not remember seeing a drawing during the left/right task.

The same 10 practice items that were used on the object decision task were presented initially on the recognition test, followed by 20 studied and 20 nonstudied target figures. Drawings remained on the screen for 5 sec, and subjects were instructed to respond before the object disappeared from the screen. Patients indicated their yes/no response verbally, whereas control subjects pressed the left key to indicate a "yes" response and the right key to indicate a "no" response.

After conclusion of testing, subjects were debriefed concerning the nature of the experiment.

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PRIMING OF NONVERBAL INFORMATION AND THE NATURE OF IMPLICIT MEMORY

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I. Introduction

Implicit memory refers to the unintentional retrieval of information that was acquired *during* a specific episode *on* tests that do *not* require conscious recollection of that episode (Graf & Schacter, 1985; Schacter, 1987). Systematic investigation of implicit memory represents a relatively new research direction in cognitive psychology and neuropsychology. Psychological studies have been traditonally concerned with explicit memory—intentional, conscious recollection of recent events—as expressed on standard recall and recognition tests. During the past several years, however, there has been a virtual explosion of research concerning various kinds of implicit memory, stimulated largely by studies that have shown that implicit memory can be dissociated sharply from explicit remembering. The dissociations have been produced both by a variety of experimental manipulations in normal subjects and by demonstrations that amnesic patients show intact implicit memory despite impaired explicit memory (for review, see Richardson-Klavehn & Bjork, 1988; Schacter, 1987; Shimamura, 1986).

Various forms of learning and retention can be grouped under the general descriptive heading of "implicit memory," including such phenomena as skill learning and conditioning (see Schacter, 1987). Perhaps the most intensively studied type of implicit memory, however, is known as repetition or direct *priming* (e.g., Cofer, 1967; Tulving & Schacter, 1990). Priming refers to a facilitation in performance that is attributable to prior study of a particular set of target items; priming need not and frequently does not involve any conscious recollection of the targets or the study episode in which they were encountered. The target items in priming experiments are typically familiar words, pseudowords, paired associates, and other verbal materials. The heavy emphasis on verbal information in priming studies may be partly attributable to the historical links between research on priming phenomena and concern with issues of lexical representation and access (e.g., Kirsner & Smith, 1974; Morton, 1979; Scarborough, Gerard, & Cortese, 1979; see Schacter, 1987); it may also be partly attributable to the attention devoted to priming recently by "mainstream" memory researchers, who have traditionally used words and word pairs as target items in explicit memory experiments (e.g. Tulving, 1983).

Although priming research has focused on verbal information, it has not done so exclusively: A number of studies have documented and explored priming of nonverbal information. We think that such studies are important for at least four reasons. First, the preoccupation with words and similar verbal items that characterizes a good deal of past and present priming research will likely produce a rather narrow view of the properties and features of *implicit* memory. Therefore, at this relatively early stage of research it is desirable and perhaps necessary to establish a broad data base in order to delineate critical characteristics of relevant phenomena. A second and related point is that a narrow empirical focus may also be theoretically misleading. Models of priming and implicit memory that are based exclusively on studies of verbal materials could well be led astray by an undue reliance on phenomena that reflect idiosyncratic properties of verbal information. Third, just as research on lexical priming has provided links between studies of memory and language (e.g., Kirsner & Dunn, 1985), research on priming of nonverbal information could help to build bridges between studies of memory and perception (e.g. Schacter, Cooper, & Delaney, 1990). Fourth, it seems clear from an evolutionary perspective that memory did not evolve initially to deal with verbal information; memory for nonverbal information must represent an earlier evolutionary achievement than memory for verbal information (e.g., Rozin, 1976). Since there are good reasons to believe that the evolutionary process of natural selection has shaped the architecture of memory systems (Sherry & Schacter, 1987) and that the memory systems involved in priming are relatively primitive both phylogenetically and ontogenetically

Schacter, 1990), a theoretical and empirical concern with priming of nonverbal information seems particularly appropriate.

In this chapter we review existing evidence on priming of nonverbal information, discuss methodological, conceptual, and theoretical issues that arise from this research, and sketch a preliminary framework for conceptualizing relevant phenomena that integrates implicit memory research with recent neuropsychological studies of perceptual disorders that are produced by brain damage.

II. Review of the Experimental Evidence

We now turn our attention to experimental data on priming of various kinds of nonverbal information. It should be noted from the outset that we focus largely on studies of repetition or direct priming that conform to what we will call the *study–test* paradigm. In a prototypical study–test procedure, a set of items is initially presented to subjects, followed by a delay that is usually measured in minutes, days, or weeks; then a test is given in which subjects perform a task that does not make explicit reference to or require conscious recollection of the previously presented items. Priming is typically revealed by faster or more accurate performance on previously studied items than on nonstudied or baseline items. We will pay relatively little attention to studies in which primes and targets are separated by extremely brief delays on the order of milliseconds. Although several such studies using nonverbal information have been reported (e.g., Bharucha & Stoeckig, 1986, 1987; Henderson, Pollatsek, & Rayner, 1987; Humphreys & Quinlan, 1988), this type of priming involves a rather different set of issues, paradigms, and perhaps mechanisms than those that are of principal concern to us (for review, see Farah, 1989).

Our review is divided into three major sections, corresponding to the three types of materials that have been used most often in studies of nonverbal priming: familiar objects, novel objects and patterns, and familiar and unfamiliar faces. After considering relevant studies, we discuss a number of methodological and conceptual issues that emerge from the review.

A. Priming of Familiar Objects

In studies concerned with priming of familiar objects, subjects are typically exposed first to pictures or line drawings that contain two-dimensional representations of familiar three-dimensional objects—either aniexperiments, priming is later assessed by requiring subjects to identify some sort of perceptually degraded stimulus: either a *nonverbal* item such as an incomplete, fragmented, or briefly presented drawing of an object, or a *verbal* item such as a fragmented or briefly presented word. We consider first studies of the former type and then discuss studies of the latter type, which focus on issues of transfer between pictures and words.

I Neuropsychological and Developmental Evidence

Although intensive experimental scrutiny of priming and implicit memory phenomena represents a relatively recent development, a number of relevant studies were reported prior to the recent surge of interest. Perhaps the earliest of them were studies by Heilbronner conducted in the first decade of the twentieth century (cited in Milner, Corkin, & Teuber, 1968; Parkin, 1982). Heilbronner used a picture-fragment completion task in which brain-damaged and normal subjects were initially shown a series of fragmented pictures of common objects and were asked to identify each object; if they were unable to identify an object from a particular fragment, a series of less fragmented pictures was presented until identification was achieved. When subjects again attempted to identify picture fragments after a delay, Heilbronner observed significant savings in identifying previously presented fragments on the second test. This procedure, which came to be known as "Heilbronner's method," was used in a study of three Korsakoff amnesics by Schneider (1912, cited in Parkin, 1982; Kinsbourne, 1989). He found that amnesics exhibited significant savings in identifying previously exposed fragmented pictures across retention intervals ranging from 7 days to 4 months—even though the patients apparently claimed that they had never seen the pictures previously. This observation thus constitutes an early example of what we would now refer to as a dissociation between implicit and explicit memory.

There was apparently little attempt to follow up Schneider's intriguing observations, but a number of similar studies of amnesic patients were reported before the "modern era" of research on implicit memory. Williams (1953) required 31 patients with memory disturbances and 20 control subjects to name a graded series of inkblot silhouettes of familiar animals; each successive silhouette approximated more closely the shape of the target animals. Free recall and "prompted recall," where silhouettes were presented again for identification, were tested after delays of 2 hr and 7 days. Although memory-disordered patients performed at near zero levels on the free recall test, they performed relatively well on the prompted recall test, particularly at the 2-hr delay. Note, however, that

on the prompted recall test, subjects were given explicit memory instructions to try to remember which previously shown animal was represented by the silhouette (Williams, 1953, p. 15). In addition, no information was presented concerning the severity of memory disorders in the patient group. Therefore, it is not clear whether Williams' results should be attributed to priming or to explicit memory. Talland (1965) described similar results in his classic monograph on Korsakoff's syndrome. He presented 14 Korsakoff patients with pictures of familiar objects that were fragmented to different degrees and presented briefly on a tachistoscope for varying amounts of time. Talland reported that previously exposed pictures were identified more readily on a subsequent test than were a novel set of similar fragmented pictures. However, Talland made no mention of any dissociation between this priming effect and patients' inability to recollect their prior experiences. Instead, he simply noted that "Amnesic patients are evidently able to form and retain for a while memory images, in the sense that other persons do" (p. 170).

Probably the best-known study on priming of familiar objects in amnesic patients was reported by Warrington and Weiskrantz (1968), who used the graded series of fragmented pictures developed by Gollin (1960) together with a procedure similar to the one used by Heilbronner and by Schneider. Each of six amnesic patients was presented on an initial trial with the most incomplete version of an object, followed by increasingly less fragmented instances until identification was achieved. The identical procedure was then repeated on four subsequent trials within the same day; five further trials were given on a second and a third day of testing, respectively. Warrington and Weiskrantz (1968) found that all of the amnesic patients exhibited considerable savings—that is, priming—across trials and days. They argued that their findings show long-term retention of specific objects by amnesic patients, and not some sort of nonspecific practice effect, because no improvements in identification performance were observed when fragments of different objects were presented on successive trials. Significantly, however, the learning or priming exhibited by the amnesic patients, though substantial, was not normal: control subjects showed consistently higher levels of identification performance than did amnesics. Although Warrington and Weiskrantz did not distinguish explicitly between the form of memory tapped by the identification task and the form of memory involved in standard recall and recognition tests, they did point out that ". . . in addition to the rapidity and uniformity in learning this task, patients find it a much less exacting test of memory than more conventional ones. They treat it more as a 'guessing game' than a formal test of memory" (1968, p. 974).

Milner *et al.* (1968) used the Gollin figures and a procedure similar to the one described by Warrington and Weiskrantz in a study of the densely amnesic patient H.M. (Scoville & Milner, 1957). In their experiment, a 1-hr delay intervened between initial presentation of the fragmented pictures and the second presentation or test. Milner *et al.* reported a 48% reduction in H.M's identification errors from initial presentation to test. This facilitation or priming effect was observed even though H.M. ". . . did not remember having taken the test before" (1968, p. 230). Consistent with the data of Warrington and Weiskrantz, however, the priming effect observed in H.M. was not normal: a group of 10 matched control subjects showed a 77% reduction in error rate under identical experimental conditions. Milner *et al.* argued that normal subjects showed a larger facilitation because they made use of "verbal [explicit] memory" (1968, p. 231) abilities not available to H.M. in order to retrieve object names and thereby supplement identification performance.

Priming of familiar objects has been observed in amnesic patients with a number of procedures other than the fragmented-pictures task. Warrington and Weiskrantz (1978) reported a study using the McGill Anomalies Test, in which a picture of an otherwise common scene contains a familiar object in an inappropriate place. Warrington and Weiskrantz (1978) recorded the time it took for amnesic patients to detect the anomalous object and found that they did so more quickly on their second attempt than on their first (see also Baddeley, 1982). Meudell and Mayes (1981) reported a similar finding with a task that involved finding a hidden object in a cartoon. They further found that amnesic patients did not discriminate between previously presented and new cartoon pictures when tested with an explicit recognition test. Crovitz, Harvey, and McClanahan (1981) presented eight amnesic patients of mixed etiologies with two pictures containing hidden figures (e.g., a cow) that are typically not perceived immediately on initial viewing (Carmichael, 1951; Dallenbach, 1951) and noted the time required to perceive the figures. Twenty-four hr later, two old and two new hidden figures were presented and patients again attempted to spot them. Crovitz *et al.* found that patients perceived the old figures much more quickly on the second presentation than on the first, and more quickly than new figures, even though several patients expressed no explicit recollection for the initial presentation of the figures. These results thus demonstrate a relatively long lasting item-specific priming effect. However, Crovitz *et al.* did not include a control group in their study, so it is difficult to know whether amnesic patients exhibited normal priming on this task

Perhaps the most important finding from these neuropsychological studies is that priming of familiar objects can be observed even when recall and recognition are reduced or absent, thereby indicating that such priming cannot be based solely on explicit memory processes. On the other hand, in most of the published studies, priming effects in amnesic patients are smaller than those observed in control subjects; we shall return to this point later.

Relevant evidence has also been provided by studies in which priming of familiar objects has been observed in young children and older adults whose performance on explicit memory tests is impaired. The first developmental study concerning what we would now call priming of familiar objects was reported by Gollin (1960) in an article that described the fragmented pictures that have come to be known as the Gollin figures. Gollin exposed a series of increasingly complete fragments of familiar objects to 4- to 5-yr-old children and adults and noted how much information was required to achieve identification of the object. He then re-presented old fragments together with new picture fragments than had not been presented previously. Gollin found that both children and adults required less information to identify old than new fragments, the magnitude of this savings or priming effect appeared to increase as a function of the similarity between study and test fragments, and there was even savings in identifying new or nonpresented fragments. These results suggest that children acquired general skill at the fragment completion task as well as specific information about individual objects. However, no explicit memory tests were used, so it is difficult to know whether the observed item-specific effects were attributable to priming or explicit remembering (see also Gollin, 1961, 1962, 1965, 1966).

Parkin and Streete (1988) used the fragmented-pictures paradigm to investigate priming and explicit memory in 3-, 5-, and 7-yr-old children as well as adults. Pictures were initially presented in their most incomplete form, followed by presentation of progressively more complete fragments until identification was achieved. Old and new picture fragments were then presented after retention intervals of 1 hr and 2 weeks. Results indicated that younger children initially required more trials to achieve identification than did older children and adults. To avoid potential confoundings attributable to this baseline difference, Parkin and Streete evaluated priming by expressing savings in identification performance on the second presentation of a fragment as a proportion of identification performance on the first presentation. This proportional analysis revealed significant priming in all subject groups and, most importantly, no effect of age on the magnitude of priming. Results also indicated that the priming effect was attributable to the acquisition of item-specific information and not to the acquisition of general skill: Exposure to fragmented pictures did not facilitate subsequent identification of new pictures. In contrast to the priming results, there was a large effect of age on a yes/no recognition test, with levels of explicit memory increasing steadily from the 3-yr-olds to the adults. The magnitude of priming declined between the 1 hr-to-2 week retention interval in all subject groups (though not as much as recognition), but each age group still showed considerable priming even at the long delay.

Carroll, Byrne, and Kirsner (1985) investigated priming in 5-, 7-, and 10-yr-old children with a paradigm in which subjects studied common objects in various conditions and then named pictures of old and new objects. Priming on this task is indicated by faster naming of old than new objects. Although older children were somewhat faster overall than were younger children to name both old and new pictures, all age groups showed a priming effect of comparable magnitude. In contrast, recognition accuracy increased systematically as a function of increasing age. These data are thus consistent with Parkin and Streete's results insofar as they show a developmental dissociation between implicit and explicit memory. Note, however, that Carroll *et al.* (1985) assessed priming with a *latency* measure and explicit memory with an *accuracy* measure. It is possible that priming would have shown a developmental trend comparable to that observed on the recognition task if it, too, had been assessed with an accuracy measure.

A dissociation between priming and explicit memory for familiar objects has also been observed in research on elderly adults. Mitchell (1989) examined the performance of old and young subjects on a picture-naming task in which old and new items were intermixed in a single long list. Target pictures were named on an initial presentation and then were named again after lags consisting of 5, 25, or 50 intervening items. Mitchell observed a robust facilitation of naming latency in young and old subjects at all lags, although there was some decrease in facilitation as lag increased. Most importantly, the magnitude of this priming effect was equivalent in the young and old subjects, even though older subjects were impaired significantly on explicit tests of memory. The elderly recalled fewer picture names than did the young and also performed less accurately on a yes/no recognition test for the prior occurrence of the pictures. As in the Carroll *et al.* (1985) study, however, the apparent implicit/explicit dissociation could also be interpreted as a dissociation between accuracy and latency measures.

Despite some interpretive problems, the foregoing studies of young children and elderly adults extend the neuropsychological evidence by showing robust priming of nonverbal information in subject groups characterized by impaired performance on explicit memory tests. This pattern of dissociation is, in turn, generally consistent with the larger literature on priming of words and other familiar verbal items in amnesic and elderly subjects who show deficits on explicit tests (see Schacter, 1987; Shimamura, 1986).

2. *Evidence from Normal Young Adults*

The studies discussed in the preceding section were concerned mainly with priming in memory-impaired populations. Nevertheless, they also demonstrated priming of familiar objects in normal adults who acted as control subjects. An early study that can be interpreted as demonstrating object priming in normal subjects was reported by Leeper (1935), who found that exposure to fragmented pictures of objects facilitated subsequent perception of the objects even after a retention interval of approximately 3 weeks. More recently, several studies have provided evidence on the separability of priming and explicit memory that complements the evidence discussed in the previous section by showing that object priming and explicit memory can be dissociated experimentally in normal young adults.

Carroll *et al.* (1985, Experiment 1) examined the effects of two types of study processing on subsequent picture-naming latency and recognition performance in college students: a deep or elaborative encoding task in which subjects judged whether target objects are animate or inanimate, and a shallow encoding task in which they attempted to find a small inked-in cross that had been drawn on the contour of some of the objects. As expected, recognition memory was more accurate following deep than shallow encoding. Despite this difference in explicit remembering, however, picture-naming latencies were facilitated equally following the two encoding tasks. As noted earlier, however, interpretation of results from this study is not entirely straightforward, because recognition was assessed with an accuracy measure and priming was assessed with a latency measure. It is conceivable that if priming had been assessed with an accuracy measure, the levels-of-processing manipulation would have influenced the magnitude of priming, just as it influenced recognition accuracy; alternatively, if recognition had been assessed with a latency measure, it might have been insensitive to the levels-of-processing manipulation, as was observed for priming. Moreover, in other experiments with children Carroll *et al.* (1985, Experiments 3 & 4) observed a levels-of-processing effect on naming latency; however, the effect was not observed when baseline differences among experimental conditions were removed. This inconsistent pattern of results highlights the need to treat Carroll *et al.*'s data with interpretive caution.

Mitchell and Brown (1988) also compared picture-naming latencies and recognition accuracy in an experiment with college students. Subjects named pictures of familiar objects in an initial session; the pictures were then re-presented for naming (intermixed with new pictures) after retention intervals ranging from 1 to 6 weeks. Explicit memory was assessed with a standard yes/no *recognition* test. Mitchell and Brown observed that initial naming of a picture facilitated subsequent naming performance by about 70 msec at all retention intervals. Recognition memory, by contrast, declined significantly across delays. Mitchell and Brown also observed that the magnitude of the priming effect was independent of whether or not subjects made accurate recognition judgments. This finding thus extends previous reports of stochastic independence between word priming and explicit memory (e.g., Hayman & Tulving, 1989; Jacoby & Witherspoon, 1982; Tulving, Schacter, & Stark, 1982). However, this study is also characterized by the questionable comparison of accuracy and latency measures discussed earlier.

A recent experiment in our laboratory has provided evidence of dissociation between *implicit* and *explicit* memory for familiar objects under conditions in which similar measures were used to assess both types of memory (Schacter & Merikle, in preparation). This study, like the experiments by Carroll *et al.* (1985), examined the effects of a levels-of-processing manipulation on priming and explicit memory. Subjects were exposed to line drawings of familiar objects and performed either a *semantic* orienting task, in which they generated functions for the depicted object, or a *structural* orienting task, in which they counted the number of vertices in each object. Priming was assessed by presenting perceptual fragments of studied and nonstudied objects. Fragments were selected that preserved minima of curvature in the object contour, thereby providing useful perceptual information about each object [the fragments and corresponding drawings were selected from various sources by Merikle & Peterson (in preparation)].

In previous studies using fragmented pictures of objects, including those discussed earlier, priming has been assessed by requiring subjects to try to identify each object (e.g., Hirshman, Snodgrass, Mindes, & Feenan, in press; Snodgrass, 1989; Warrington & Weiskrantz, 1968; Weldon & Roediger, 1987). Unfortunately, when subjects are required to identify a fragmented object, they may well attempt to make use of any kind of information that can aid identification, including episodic information that is retrieved through intentional or explicit strategies. Because most studies using fragmented pictures employ procedures akin to the ascending method of limits, where subjects are given exposure to several fragments and are allowed a considerable amount of time to try to identify them, it seems quite likely that standard picture-fragment paradigms encourage the use of explicit memory strategies. The fact that amnesic patients do not show entirely normal priming in the picture-fragment completion task

is consistent with the idea that this task typically involves an explicit memory component.

We attempted to overcome these problems and reduce the contribution of explicit memory to fragment completion performance by altering fragment completion instructions so that subjects were told to respond quickly to each perceptual fragment with *the first object that comes to mind* (see also Heindel, Salmon, & Butters, in press) and were also told that there was no correct/incorrect response on the task. A separate group of subjects was given the same perceptual fragments together with explicit memory instructions to try to remember the correct object from the study list. Results revealed that the magnitude of priming was virtually identical following the semantic and structural orienting tasks. By contrast, explicit memory performance was significantly higher following the semantic task than following the structural task. Because the same cues (i.e., perceptual fragments) were used on the implicit and explicit tasks, and performance on both tasks was assessed with the same accuracy measure, we can be confident that this pattern of results reflects a dissociation between priming and explicit memory.

An experiment by Jacoby, Baker, and Brooks (1989) provides evidence for a somewhat different type of dissociation. Subjects were exposed to pictures of common objects in two different ways: (1) pictures were fully exposed on a computer monitor for 7 sec and subjects were required to name them; (2) pictures were "clarified" by a procedure in which random noise dots were gradually replaced by dots from a target picture until subjects could name the depicted object, at which point the fully clarified picture remained on the screen for 7 sec. Memory for the pictured objects was tested explicitly with a free recall test in which subjects were instructed to remember the names of presented objects. Priming was assessed with an identification test that incorporated the clarification procedure: old and new pictures were clarified until subjects could name them, and the amount of clarification required for identification was measured. Jacoby *et al.* reasoned that the extra processing of visual detail in the clarification study condition would benefit identification performance but not free recall of the object name. Moreover, since the additional processing time in the clarification condition yielded a longer retention interval than in the full-exposure condition, there was reason to predict lower free recall performance in the former condition than in the latter. Results were consistent with these expectations: Free recall performance was higher in the full-exposure study condition than in the clarification study condition, whereas the opposite pattern of results was observed on the clarification test—there was more priming in the clarification study condition than in the full-exposure study condition.

The dissociations observed in the foregoing experiments, together with the neuropsychological and developmental evidence, suggest that different mechanisms are involved in priming and explicit memory for familiar objects. A number of studies have provided information about the properties of the representations and processes that support priming. Lachman and Lachman (1980), for example, examined the extent to which priming on a picture-naming task is based on encoding the *visual* properties of objects, as opposed to encoding or activating the lexical information represented by the object's name. To investigate the issue, they examined performance on a yes/no recognition test that included previously studied objects as well as new objects. The actual purpose of the recognition test was to induce subjects to encode the visual properties of objects without requiring overt production of object names; that is, Lachman and Lachman assumed that making a yes/no judgment about the prior occurrence of an object would not entail overt naming of the object. The critical items in the experiment were thus the new or lure objects that had not been presented previously. These lure objects were subsequently presented with a set of entirely new objects on a picture-naming task. Lachman and Lachman found that subjects named the objects that had appeared previously as lures on the recognition test faster than the entirely new objects, thus suggesting that object priming can occur even when subjects do not name the objects at the time of encoding. Unfortunately, no systematic evidence was presented to show that subjects did not in some manner activate the object's name during the recognition test. Nevertheless, these data do show that priming of picture naming need not involve prior *overt* naming of objects during an encoding task. On the other hand, Lachman and Lachman also found that the magnitude of the priming effect on naming latency depended on properties of the object name: Objects that elicited the same name from virtually all subjects appeared to produce less priming than objects that elicited several different names. In addition, some priming of picture naming was observed following processing of the picture name alone, but not nearly as much as was observed following presentation of the picture itself.

A related series of experiments has investigated questions concerning the *specificity* of priming effects with familiar objects: Is the phenomenon based on the activation of some sort of generic or abstract code that represents an object's prototypical features, or does priming reflect specific characteristics of the particular object encoded by the subject on a study trial? Two types of evidence are relevant to this question. First, as noted earlier, in a developmental study Gollin (1960) found that initial "training" on a fragmented version of a picture produced greater subsequent savings (priming) in identifying that fragment than did initial training by exposure to the entire picture. More recently, Snodgrass and Feenan (1989) have replicated and extended these findings with adults and have also shown that priming is greater when the same picture fragment is presented for identification at study and test than when different fragments are used, although there was still significant priming in the different-fragment condition. These kinds of results suggest that priming is based at least in part on a representation of the specific features of objects presented for study, and not solely on an abstract or generic object code. However, explicit memory processes may have played some role in the observed specificity effects. As noted earlier, when training procedures like those in the Gollin and the Snodgrass and Feenan studies are used, explicit memory likely contributes to savings on the identification test (Snodgrass, 1989; Snodgrass & Feenan, 1989). The results of Jacoby *et al.* (1989) with the clarification procedure at least partly address this issue, because they observed specificity effects on an identification test—maximal priming when objects were identified via the clarification technique at both study and test—even though free recall was lower when pictures were studied by "clarification" than with full exposure. Accordingly, it seems unlikely that those explicit memory processes that underlie *free recall of an object's name* contributed to the specificity effect on priming. However, this study provides only partial and equivocal evidence that the specificity effect is attributable to priming and not to explicit memory. It is quite possible that if Jacoby *et al.* had assessed explicit remembering with a recognition test in which subjects were given the same nominal cues as on the identification test, together with intentional retrieval instructions, specificity effects might well have been observed.

A somewhat different type of specificity effect was reported in an early study by Bartram (1974) in which subjects named photographs of familiar objects across blocks of trials. Following the initial naming of an object, there were four critical experimental conditions: (1) the same object was presented again in the same view as on initial presentation; (2) the same object was presented again, but photographed from a different view than on initial presentation; (3) a physically different object with the same name as the target was presented (e.g., photographs of two different cups were named at study and test); and (4) a photograph of a physically different object with a different name was presented. Relative to the baseline level of performance in Condition 4, naming latencies were significantly faster in each of the first three conditions, thereby indicating the presence of priming. Most importantly, however, the largest priming effect was observed for identical objects, less priming occurred for the same object from a different view, and the least amount of priming was found for different objects with the same name (see also Bartram, 1976).

Warren and Morton (1982) reported a similar pattern of results in a study in which subjects initially named either pictures of objects or their verbal labels (e.g., a picture of a clown or the word *clown*). Subjects were then given brief tachistoscopic exposures to pictures and were required to identify them. Some pictures were identical to those named initially, some depicted different objects with the same name (e.g., a picture of a different clown than had been studied), and some had not been previously studied. In their first experiment, Warren and Morton observed significant priming of identical pictures together with a nonsignificant trend for priming of same-name pictures. They argued that the failure to observe significant priming of same-name objects was attributable to the use of explicit memory strategies. According to Warren and Morton (1982, p. 122), if some subjects used an explicit retrieval strategy of attempting to "match" the test picture with a previously studied picture, they would be less likely to find an acceptable match when same-name (but different-object) pictures were exposed. In a second experiment, they attempted to reduce the contribution of explicit memory to picture-identification performance by increasing the length of the study list and testing only a small proportion of the study list items. The obtained pattern of results was quite similar to those observed in the first experiment, except that now the priming effect in the same-name condition was statistically significant. In addition, there was greater priming in the identical condition than in the same-name condition, thus providing some evidence for specificity. Finally, Warren and Morton also observed in both experiments that naming a picture's verbal label at the time of study produced *no* priming on subsequent identification performance, a finding that we shall elaborate on in the next section of the article. Consistent with the results of Warren and Morton, Jacoby *et al.* (1989) found evidence for priming in both identical and same-name conditions with their picture-clarification procedure but also reported more priming in the former condition than in the latter.

The foregoing studies thus suggest that at least some of the priming effect observed on identification and naming tasks is attributable to an encoded representation of the specific object presented at the time of study (more priming in identical than in same-name condition); however, these studies also suggest that priming may be based in part on the activation of a more abstract object representation (significant priming in the same-name condition). Nevertheless, interpretation of these results is not entirely straightforward, because the contribution of explicit memory processes has not been sufficiently scrutinized. It is possible that the observed specificity effects are attributable to explicit memory processes,

perhaps because priming in a same-name condition is reduced by subjects' use of intentional retrieval strategies, as suggested by Warren and Morton.

A recent study in our laboratory addresses this issue directly (Schacter & Bowers, in preparation). Subjects were shown pictures of familiar objects and performed either a semantic orienting task (function generation) or a structural orienting task (vertex counting), as in the previously described study by Schacter and Merikle (in preparation). After a delay of several minutes, subjects in both groups were given a priming task in which pictures of objects were exposed for 50 msec (preceded and followed by a pattern mask) and subjects attempted to identify them. The tested objects were (1) *identical* to a previously studied object, (2) different exemplars of the object that had the *same name*, or (3) *new* objects that had not been previously studied. After the identification test, subjects were shown the same pictures and were asked to make yes/no recognition judgments about whether they had seen an object of the kind depicted by the picture on the initial study list (i.e., "yes" responses were correct for both identical and same-name objects).

The experiment yielded three important results. First, recognition memory performance for both identical and same-name objects was significantly higher in the semantic encoding condition than in the structural encoding condition. Second, the magnitude of priming for identical objects did not differ in the semantic and structural conditions: Identification accuracy increased from about 70% for new objects to about 85% for identical objects in both encoding conditions. Thus, the levels-of-processing manipulation produced an implicit/explicit dissociation on the object-identification task, just as it did on the object-completion task used by Schacter and Merikle (in preparation). Third, and perhaps most important, there was *no* priming of same-name objects in the structural condition, together with a marginally significant trend for priming of same-name objects in the semantic condition. The failure to observe any priming of same-name objects following structural encoding is particularly important: If, as suggested by Warren and Morton (1982), explicit memory somehow inhibits priming in a same-name condition, then more priming of same-name objects should have been observed following structural encoding than following semantic encoding, because explicit memory was lower in the former than in the latter condition. However, an opposite pattern of results was observed. Contrary to Warren and Morton, then, our data suggest that facilitation of identification performance for same-name objects may be *attributable to*—rather than *inhibited by*—explicit memory processes and that "genuine" structurally based priming is restricted to identical objects. Of course, it will be necessary to replicate these findings before firm theoretical conclusions can be drawn.

Suggestive evidence concerning the specific type of structural information involved in object priming is provided by Biederman and Cooper (1989b). In an initial experiment, subjects named contour-deleted objects from brief presentations during the first block of trials. On the second block, three types of objects were named: some were *identical* to those named on the first trial (i.e., same object, same contour deletion), some were *complements* of the object named on the first trial (i.e., same object, composed of edges and vertices that were deleted on the initial trial), and some were different objects with the *same name*. Biederman and Cooper observed some priming (faster and more accurate naming) for same-name objects, which they attributed to nonvisual factors (e.g., name or concept priming). More importantly, they observed significantly greater priming for identical and complementary objects, with no difference between these two conditions. The latter finding indicates that priming is not based on some sort of "literal" representation of object features, because objects in the identical and complementary conditions were composed of entirely different contours yet showed equivalent priming. By contrast, in a second experiment Biederman and Cooper constructed complementary objects by deleting alternate convex components or geons (Biederman, 1987) and found significantly less priming in the complementary condition than in the identical condition. Indeed, there was no more priming in the complementary condition than in the same-name condition.

Biederman and Cooper's results suggest that object priming may depend critically on the encoding of structural components of objects. However, two points about their study should be noted. First, they did not include an explicit memory test in either experiment, so we do not know whether and to what extent explicit memory processes contributed to the observed pattern of results. Second, they presented no evidence to support their assumption that priming in the same-name condition is based exclusively on nonvisual information. As noted earlier, Warren and Morton have argued that priming in this condition reflects priming of an abstract, but visual, representation of an object. However, the Schacter and Bowers finding discussed earlier that there is no priming in a same-name condition following a structural encoding task does provide some support for Biederman and Cooper's claim.

In a related study, Biederman and Cooper (1989a) found that priming in their paradigm was unaffected by changes in retinal location (i.e., hemifield of presentation) and left/right orientation of an object between first and second naming trials, even though subjects possessed relatively good explicit memory for location and orientation information. Although these

results suggest that object priming is based on an orientation-free representation, Jolicouer (1985) has reported effects of orientation change on priming of naming latencies. In an initial experiment, Jolicouer showed that the time to name drawings of familiar objects increases linearly as the objects are rotated increasingly further from upright. More importantly for the present purposes, Jolicouer showed in two additional experiments that this effect of orientation decreases with practice at naming rotated objects. The effect of practice was item specific, in the sense that repeated naming of rotated objects did not reduce the effect of orientation on novel objects; the effect was observed only for rotated objects that were previously named.

Jolicouer and Milliken (1989) have extended these results to show that initial naming of objects in various rotations reduces subsequent effects of orientation on naming times of previously presented objects relative to a condition in which objects are initially only in upright form. To the extent that the "practice" effects observed by Jolicouer can be taken as expressions of priming, these data suggest that information about the orientation of familiar objects plays a role in priming of naming latencies. Although this conclusion may appear inconsistent with Biederman and Cooper's (1989a) findings, these investigators examined effects of left/right orientation changes, whereas Jolicouer has focused on changes from upright orientation. It should also be noted that information about orientation appears to play an important role in explicit memory performance (Rock & DiVita, 1987; Rock, DiVita, & Barbeito, 1981), so detailed comparisons of the effects of orientation change on priming and explicit memory are clearly necessary in order to understand more fully the role of orientation information in implicit and explicit memory for familiar objects.

3. *Picture/Word Transfer*

A number of studies concerned with priming of nonverbal information have examined transfer of priming between pictures of familiar objects and the corresponding object names. Perhaps the earliest such study was reported by Winnick and Daniel (1970). In their experiment, subjects were exposed to pictures of familiar objects or to words corresponding to the pictured objects. Priming was assessed with a word-identification test and explicit memory was assessed with a free recall test. Winnick and Daniel observed a striking dissociation between these two memory tests: Free recall was higher following study of a picture than study of the corresponding word, but priming effects on the word-identification test were greater following study of the word than study of the picture. Indeed, there was only a slight priming effect in the pictorial study condition.

Although Winnick and Daniel's findings were largely overlooked in subsequent years (see Roediger & Weldon, 1987; Schacter, 1987), they were confirmed and extended by two studies that appeared nearly a decade later. Scarborough *et al.* (1979) required subjects to name concrete words or corresponding pictures and then examined performance on a lexical decision test in which words from the two study conditions (as well as new words and nonwords) were presented, and subjects decided as quickly as possible whether each letter string constituted a word or a nonword. Prior study of a word produced significant facilitation of lexical decision latency, but prior study of pictures produced no priming. In contrast, a subsequent experiment showed that recognition memory was higher for previously studied pictures than words, thus providing a dissociation similar to that observed by Winnick and Daniel. Consistent with the results of Scarborough *et al.*, Durso and Johnson (1979) found that initial naming of a picture produced no priming of naming latency when subjects subsequently named the corresponding word, although considerable priming was observed when the same picture was named again. However, Durso and Johnson also reported an asymmetry in priming: Initial naming of a word facilitated subsequent naming of the pictorial equivalent, although priming was not as robust as in a word–word condition. Durso and Johnson found a similar pattern of results with a task that involved repeated categorization of words and pictures. Consistent with these results, it was noted earlier that Lachman and Lachman (1980) found that study of words produced significant, albeit reduced, priming on a subsequent picture-naming task relative to study of their pictorial equivalents. Warren and Morton (1982), however, found that studying words produced no priming on a subsequent test of picture identification from brief tachistoscopic exposures.

The foregoing experiments suggest that there is little if any priming from pictures to words on a variety of tests. Some picture–word priming has been documented, however, in subsequent studies. Kroll and Potter (1984) required subjects to make "reality" decisions concerning whether letter strings represented real words or nonwords and whether line drawings represented real objects or nonobjects. Large repetition priming effects on decision latencies were observed in word–word and picture–picture conditions. Significant, albeit substantially reduced, priming was found from pictures to words. In contrast to previous studies, however, no priming was found from words to pictures. Kirsner, Milech, and Stumpfel (1986) examined priming on a tachistoscopic word-identification test following a study task in which subjects classified words on their pictorial equivalents as living or man-made. Significant priming was found in both the word–word and the picture–word conditions, although the former condition yielded more priming than did the latter. When a study task was used that required subjects to judge the real-world size of words or pictorial equivalents, similar amounts of priming were found on a subsequent word-identification test. However, Kirsner *et al.* also showed that the "intramodal" component of priming (i.e., word–word transfer) could be dissociated from the "intermodal" component (i.e., picture–word transfer), inasmuch as a word frequency manipulation affected the intermodal but not intramodal type of priming. Kirsner *et al.* also showed that studying pictures yielded higher levels of explicit memory on a yes/no word-recognition test than did studying words, in contrast to the priming data.

Weldon and Roediger (1987) examined the effects of studying words or their pictorial equivalents on two subsequent tests: word-fragment completion and free recall. They observed a striking crossover interaction between the two tests similar to the pattern first reported by Winnick and Daniel; free recall performance was higher for pictures than for words, whereas there was greater priming on the fragment completion test for words than for pictures. Weldon and Roediger found that studying pictures produced some priming on the fragment completion test, but the effects were quite small. Conversely, additional experiments showed that studying pictures of objects produced large priming effects on a picture-fragment completion test.

Hirshman *et al.* (in press) reported several experiments that used a study task in which subjects studied target words by generating a sentence that contained each word. Priming was assessed with a picture-fragment completion task using the ascending method of limits procedure described earlier (e.g., Gollin, 1960; Snodgrass, 1989). Hirshman *et al.* observed significant word–picture priming in this experiment and two similar ones, and on the basis of these results argued for a conceptual component to priming. Several features of this study, however, limit the force of this conclusion. First, Hirshman *et al.* did not use a picture–picture condition, so we do not know whether the word–picture priming effects that they observed were smaller than picture–picture priming effects, as has been observed previously. Second, and perhaps more importantly, it was noted earlier that when priming on a picture-fragment completion task is assessed with the ascending method of limits, as was done in the Hirshman *et al.* study, explicit retrieval processes likely play a major role in task performance. Thus, the word–picture transfer reported by these investigators may be entirely or largely attributable to explicit retrieval. Hirshman *et al.* attempted to deal with this possibility by comparing performance on the picture-fragment completion task and a free recall task (in which subjects recalled target words). They found little correlation between free recall and picture completion performance and thus argued that word–picture priming is not attributable to explicit memory. Unfortunately, this line of reasoning is not compelling, because the same outcome might have been observed even if subjects had in fact treated the picture completion test as an explicit cued recall test: that is, free recall of words and explicit cued recall of pictures may not be strongly correlated. As discussed elsewhere in this article, to evaluate the possible contribution of explicit memory to a priming effect on an allegedly implicit task, it is necessary to use the same nominal cues on the two tasks and vary only task instructions (see discussion on pp. 110–112). Comparisons of the kind made in the Hirshman *et al.* study do not speak directly to the role of explicit memory processes, so their data must be treated with interpretive caution.

Despite the variability and occasional inconsistencies among the foregoing studies, it seems safe to conclude that there is generally a good deal less priming from pictures to words and words to pictures than from words to words or pictures to pictures. Whether or not *no* intermodal priming is found, or *reduced* levels of intermodal priming are observed compared to an intramodal condition, varies across experiments and likely depends on tasks and materials in ways that are not yet well understood. Nevertheless, the generally reliable finding that priming is reduced in intermodal conditions indicates that the physical form of a stimulus plays a large role in priming. Moreover, the finding that studying familiar pictures enhances recall and recognition of corresponding words, while producing little or no priming on word identification, fragment completion, and lexical decision tests, indicates that form-based information plays a different role in priming than in explicit memory. Note, however, that the crucial importance of form information is observed only for *repetition* or *direct* priming; studies of *semantic* or *associative* priming have consistently provided evidence of extensive and even complete transfer between pictures and words (e.g., Vanderwart, 1984). We shall return to this point later when considering theoretical interpretations of nonverbal priming.

B Priming of Novel Objects and Patterns

Although the studies considered in previous sections include a wide variety of tasks, experimental procedures, and subject populations, in all experiments either the study or the test materials consisted of photographs, pictures, or line drawings of common objects. These materials are thus familiar to subjects before the initial study presentation in the sense that the objects that they depict are represented in long-term memory prior to the experiment. The fact that most studies on priming of nonverbal information have used familiar materials with preexisting memory representations has a number of theoretical implications that will be discussed shortly. Nevertheless, there have been some, albeit relatively few, studies that have examined priming of novel or unfamiliar nonverbal information.

One set of relevant findings is provided by studies of the "mere exposure" effect (Zajonc, 1980) on preference judgments. In an experiment by Kunst-Wilson and Zajonc (1980), subjects were exposed for 1 msec to line drawings of novel shapes (irregularly shaped octagons). They were then given two types of forced-choice tests: (1) a recognition test in which an old and a new octagon were presented and subjects indicated which shape had been presented previously; and (2) a preference test in which an old and a new octagon were presented and subjects indicated which shape they liked better. Since the latter task does not require conscious recollection of the study exposure, it can be viewed as an implicit memory test that may be influenced by priming. Although subjects did not perform significantly higher than chance on the recognition test, they showed a reliable preference for the previously exposed octagon. Seamon, Brody, and Kauff (1983) reported that exposure effects on preference judgments were larger when target shapes were initially exposed in the right than in the left visual field, whereas a left-visual-field advantage was observed for recognition. Johnson, Kim, and Risse (1985) found normal exposure effects on preferences for novel melodies in amnesic patients who were impaired on a recognition test, thereby providing further evidence for a dissociation between preference judgments and explicit memory.

Mandler, Nakamura, and Van Zandt (1987) questioned whether the effects observed in the foregoing studies reflect a fundamental difference between cognition (indexed by recognition memory) and affect (indexed by preference judgments), as had been argued by Zajonc (1980). As in the Kunst-Wilson and Zajonc and Seamon *et al.* studies, Mandler *et al.* gave subjects brief (2 msec) exposures to unfamiliar shapes and then tested recognition and preference judgments for old and new shapes in two different subject groups. In addition, however, Mandler *et al.* also required two other subject groups to judge which of two test stimuli (one old and one new) seemed *brighter* or which of the two seemed *darker*. Consistent with previous results, they observed a reliable preference for old shapes under conditions in which recognition memory did not differ from chance. More importantly, Mandler *et al.* also found that subjects showed a similar tendency to judge previously exposed shapes as either brighter or darker than new shapes in the appropriate conditions. These results suggest that the dissociation between preference and recognition judgments observed in previous studies is not based on a fundamental split between cognition and affect, but rather reflects a nonspecific priming effect that can be expressed in a variety of judgments independently of explicit memory.

A number of studies have examined priming of novel nonverbal information using implicit tests that are in some respects similar to the identification, completion, and lexical decision tasks that have been used extensively in the verbal domain. Two recent experiments have focused on priming of dot patterns. In a neuropsychological study of the severely amnesic patient H. M. (Gabrieli, Milberg, Keane, & Corkin, in press), the target materials were spatial arrangements of five dots from a 3 × 3 matrix that were connected by four lines to form a specific pattern. After exposing a series of such patterns to H.M. and a group of control subjects, priming was assessed with a "dot-completion" test in which unconnected five-dot arrangements were presented and subjects were asked to draw any figure that connected the dots with straight lines. There were a number of possible completions for each figure, and the question of principal interest was whether subjects would tend to connect the dots to form previously studied figures. Results indicated robust and similar levels of priming in H.M. and control subjects; dot patterns on the completion test were connected to form previously studied figures at significantly higher than baseline levels. Moreover, a dissociation between priming and explicit memory was observed: H.M. showed intact pattern priming despite his severe impairment on a recognition test in which subjects were asked to remember explicitly which patterns had been presented previously.

Musen and Treisman (1990) also examined priming of novel dot patterns with a different implicit test. In their study, college students were shown 50 dot patterns similar to those used by Gabrieli *et al.*, consisting of five dots from a 3 × 3 matrix that were connected by four lines. Priming was assessed after delays of 1 hr, 3 hr, or 7 days with a perceptual identification test in which old and new dot patterns were presented briefly, and subjects tried to copy the correct pattern on an empty 3 × 3 grid. Exposure time on the identification test was calibrated so that baseline accuracy in copying patterns without any study exposure was about 40–45% correct. Musen and Treisman observed significant priming effects in their experiment—subjects copied significantly more old than new patterns—and the magnitude of priming was largely unaffected by length of retention interval. Explicit recognition of the patterns, by contrast, declined across the delay. In addition, recognition and priming ex-

hibited stochastic independence (e.g., Tulving *et al.*, 1982): the probability of recognizing a particular pattern was uncorrelated with the probability of producing that pattern from a brief exposure.

Several other recent studies have examined priming of novel two-dimensional and three-dimensional shapes and objects. As noted earlier, Kroll and Potter (1984) examined priming with an object decision task in which subjects decided whether drawings of either familiar, real-world objects or constructed nonobjects did or did not exist in the world. Both objects and nonobjects were repeated after lags of three or ten intervening items in a continuous sequence during which subjects made object decisions. Kroll and Potter found that subjects were faster to make such decisions about nonobjects on the second presentation of a drawing than on the first; similar effects were observed for familiar objects. Thus, priming was observed in this experiment for both novel items with no preexisting memory representations and familiar items that have preexisting representations.

A rather different type of object decision task was used in a series of experiments by Schacter *et al.* (1990). The materials in these experiments were two-dimensional drawings of novel, unfamiliar three-dimensional objects. Although *none* of the target objects actually exist in the real world, half of the drawings depict structurally *possible* objects whose surfaces and edges are connected in such a way that they could exist in three-dimensional form. The other half of the drawings, in contrast, represent *impossible* objects that contain surface, edge, or contour violations that would make it impossible for them to exist in three-dimensional form (e.g., Penrose & Penrose, 1958). To assess priming of these objects, Schacter *et al.* devised an object decision test in which subjects were given brief (100 msec) exposures to possible and impossible objects and were required to decide whether each object was structurally possible or impossible; half of the test objects had been studied several minutes earlier and half were new. The main question was whether priming of novel objects would be observed—that is, whether study of possible and impossible objects increased the accuracy of subsequent object decisions. Explicit memory was assessed with a standard yes/no recognition test.

In an initial experiment, priming on the object decision task was found following a study task that was intended to induce subjects to encode information about the global three-dimensional structure of the objects (indicating whether each object faced primarily to the left or right). By contrast, no priming was observed following a study task that required encoding the local features of target objects (indicating whether each object had more horizontal or vertical lines). The magnitude of priming in the left/right condition was about the same whether or not the object decision task was preceded by a recognition task on which all critical objects were exposed; that is, mere exposure to an object on the recognition task did not produce priming on the object decision task. Priming also showed stochastic independence from recognition memory. Significantly, priming was found only for the structurally possible objects; no priming of structurally impossible objects was observed in this study or in subsequent experiments. However, recognition memory for impossible objects was only slightly less accurate than was recognition of possible objects.

The results of this experiment were interpreted as suggesting that priming on the object decision test depends on prior encoding of a global three-dimensional *structural description* (Marr, 1982; Marr & Nishihara, 1978) of target objects. By this view, the failure to find priming of impossible objects indicates that it is difficult to form a global structural description of such objects. In a subsequent experiment, the left/right encoding task was compared to an *elaborative* encoding task in which subjects had to think of a familiar object from the real world that each target object reminded them of most. As expected, this encoding task yielded higher levels of explicit memory performance on the recognition test than did left/right encoding; the elaborative task required subjects to relate target objects to preexisting semantic knowledge of objects, thus producing a distinctive and hence highly memorable episodic memory representation (e.g., Jacoby & Craik, 1979). The striking result, however, was that *no* priming was observed following the elaborative task, whereas the left/right task again produced substantial priming. One potential reason for the failure to observe priming following elaborative encoding was that subjects often produced two-dimensional elaborations of the objects and did not encode them as three-dimensional structures. In a third experiment, an attempt was made to induce subjects to achieve three-dimensional elaborations by requiring them to indicate whether each object reminded them most of a type of furniture, a household object, or part of a building. Significant priming was observed following this task; however, these priming effects were no greater than those observed following the left/right task, even though the three-dimensional elaboration task produced higher recognition performance than did the left/right task.

As noted above, the fact that priming was observed for possible but not impossible objects suggests that subjects are unable to form global structural descriptions of impossible objects. Schacter *et al.* noted, however, that a number of alternative interpretations of this finding could not be excluded. For example, the target objects for these experiments were selected initially on the basis of a pilot study in which subjects were given unlimited time to classify them as possible or impossible; only those objects that yielded high levels of intersubject agreement were included in the target set. However, whereas there was 97% agreement about the possible objects, there was less agreement (87%) concerning the impossible objects. It is thus possible that priming of impossible objects could be observed if a set of objects were used that yielded close to 100% agreement with unlimited viewing time. In more recent studies (Schacter, Cooper, Delaney, Peterson, & Tharan, *in preparation*), a new set of impossible objects that conformed to this criterion was used, and a number of other procedural changes were made to increase the likelihood of observing priming for structurally impossible objects. Nevertheless, these experiments, like the earlier studies, have yielded no evidence for priming of impossible objects—even after four repetitions of the left/right encoding task. Interestingly, four vs. one study list repetitions had no effect on priming of possible objects—similar amounts of priming were observed in both study conditions—even though explicit memory for possible and impossible objects was significantly higher following four than following one study list repetition. Thus, the overall pattern of data suggests that subjects can encode local features and parts of impossible objects that are sufficent to support reasonably high levels of recognition memory, but do not and perhaps cannot form global descriptions of impossible objects that are needed to support priming on the object decision test.

A recent study by Kersteen-Tucker (1989) has yielded a pattern of results that in some respects parallels the one observed in the foregoing experiments. Kersteen-Tucker examined priming of novel, unfamiliar polygons in a continuous-response procedure in which subjects decided whether each of a series of polygons was symmetrical or nonsymmetrical; half of the targets were symmetrical and half were not. Target polygons were repeated after lags of zero, one, four, or eight intervening items. The dependent measure was latency to make the symmetry judgment, and priming was indicated by faster response latencies to repeated than to nonrepeated polygons. Kersteen-Tucker observed a significant priming effect at all lags for symmetrical polygons, although the magnitude of the effect declined across lags. By contrast, no priming was observed for nonsymmetrical polygons, even at the zero lag. Thus, just as possible but not impossible objects showed priming on the object decision task, symmetrical but not nonsymmetrical shapes showed priming on the symmetry judgment task. However, explicit memory for the shapes was not investigated in Kersteen-Tucker's experiment.

C. Priming of Familiar and Unfamiliar Faces

There have been only a few studies concerned with priming of faces, but they have yielded several suggestive experimental facts. Bruce and Valentine (1985) reported two experiments that were motivated by Warren and Morton's work on priming of familiar objects. In their first experiment, subjects were initially presented with either pictures of familiar faces (e.g., politicians, entertainers) or the corresponding printed names. In the former condition, subjects were required to name the face; in the latter they read aloud the printed name. Priming was assessed after a 20-min filled delay with a task in which subjects were given brief exposures to faces and attempted to name them. The duration of presentation was manipulated using the ascending method of limits: Presentation of a particular face began at 10 msec and was increased by 10 msec/exposure until subjects identified the face twice in succession. Priming was assessed by comparing subjects' naming thresholds in four different conditions defined by the prior history of the faces: (1) neither the face nor name of the face had been presented in the naming phase of the experiment *(baseline)*; (2) the name but not the face had been presented *(name)*; (3) the same face had been presented *(same)*; and (4) a different view of the face had been presented during naming *(different)*. Bruce and Valentine found that, relative to baseline, comparable levels of priming were observed in the name and different conditions, while significantly greater priming was found in the same condition. These results were thus similar to the analogous picture priming data of Warren and Morton (1982), except that no priming was found in the name condition of the Warren and Morton study. Bruce and Valentine noted, however, that they might have observed priming in the name condition because a naming response was required on their test. To investigate this issue, they performed a second experiment in which priming was assessed with a familiarity test that did not require naming: Subjects had to indicate as quickly as possible whether the face was familiar to them, and the dependent variable was latency to make the familiarity judgment. Using the same four study conditions as in the first experiment, Bruce and Valentine reported significant priming in the different condition, even greater priming in the same condition, and, most importantly, no priming in the name condition. These results suggest that the priming observed in the name condition in Experiment 1 was likely attributable to a facilitation of name production.

Similar results were reported in subsequent study by Young, McWeeny, Hay, and Ellis (1986, Experiment 4). Subjects in their experiment

were initially exposed to either the faces or the names of politicians and unfamiliar people. When exposed to faces, subjects made either a *familiarity decision* (i.e., Is this face familiar?) or a *semantic decision* (i.e., Is this face a politician?). When exposed to names, they made a *name-familiarity decision* (i.e., Is this name familiar?). Priming was assessed with the semantic decision task; latency to make the semantic decision was the dependent variable. Young *et al.* found significant and comparable amounts of priming for familiar faces following both the familiarity and the semantic decision tasks; no priming of unfamiliar faces was observed following either task. In addition, no priming for either familiar or unfamiliar faces was observed following the name-familiarity judgment. Thus, as in the Bruce and Valentine study, when a face-judgment test does not require a naming response, prior exposure to a name does not produce priming.

The Young *et al.* study also suggests that unfamiliar faces, unlike unfamiliar objects, may not be susceptible to priming. This notion receives some additional support from an investigation by Bentin and Moscovitch (1988). They assessed priming with a *face-decision* task in which the critical stimuli were either pictures of normal but unfamiliar faces or faces with scrambled features ("nonfaces"). Subjects decided whether each configuration formed a normal human face or a nonface on two successive presentations of critical targets that were separated by lags of 0, 4, or 15 intervening items. Priming was observed for both faces and nonfaces only in the zero lag condition. In contrast, on an analogous lexical decision task, familiar words showed priming at all lags whereas nonwords showed priming only at lag zero. In subsequent experiments, Bentin and Moscovitch attempted to increase the "strength" of the memory representation for unfamiliar faces by varying study task and number of repetitions. Nevertheless, they found no priming of unfamiliar faces beyond lag zero on the face-decision task. However, when subjects were given an explicit recognition task, memory for the unfamiliar faces was observed even at the longest lag, thus suggesting that some sort of representation of these faces had been formed.

Both the Young *et al.* and Bentin and Moscovitch studies, then, failed to find priming of unfamiliar faces on two different types of implicit tests (semantic decision and face decision). Some unpublished data suggestive of priming for unfamiliar faces, however, was alluded to briefly in an article by Tulving (1985). In the cited experiment, subjects were initially presented with "shadow drawings" of unfamiliar faces. Priming was then assessed by presenting old and new shadow drawings and asking subjects to indicate whether or not they could "see" a face in the drawing (some drawings did not represent faces); explicit memory was assessed with a yes/no recognition test. Tulving reported that subjects correctly identified more old than new shadow faces and that this priming effect exhibited stochastic independence from recognition memory.

III. Methodological, Conceptual, and Theoretical Issues

The studies that we have reviewed indicate that priming of nonverbal information can be observed across a wide range of tasks and materials. Priming has been observed on fragment completion, picture-identification, picture-naming, object decision, preference, face-naming, semantic decision, and pattern identification/completion tasks; and priming has been demonstrated both for familiar objects and shapes as well as for novel objects and patterns that have no preexisting memory representations. We now turn to some of the major methodological and conceptual issues that arise from this literature. We consider first the possible contributions of explicit memory and naming processes, respectively, to performance in priming paradigms. We then consider alternative accounts of the phenomena that we have reviewed and conclude by outlining a preliminary theoretical framework for conceptualizing priming of nonverbal information.

A. Contributions of Explicit Memory

The studies that have been considered in this chapter all share one critical feature: They have assessed the influence of information acquired during an episode on subsequent performance with implicit memory tests that do not make explicit reference to, or require conscious recollection of the prior study episode. It is precisely because such tests have been used that we refer to the phenomena of interest as expressions of *priming* and not *remembering*. However, as indicated earlier in the article the fact that a test does not require explicit remembering of a prior episode does not preclude the possibility that subjects will make use of explicit memory processes. For example, we have noted several times that the standard picture-fragment completion task, which has been used in numerous studies of priming, is readily influenced by explicit memory processes (e.g., Snodgrass, 1989).

The possibility that explicit memory processes influence performance on nominally implicit tests raises some tricky interpretive issues. Consider, for example, the finding that amnesic patients show significant, but not normal, priming on the picture-fragment completion task (e.g., Milner *et al.*, 1968; Warrington & Weiskrantz, 1968). The fact that amnesics show *some* priming despite near chance levels of recognition performance indicates that the observed priming cannot be attributed to explicit memory. However, the additional fact that amnesic patients show lower levels of completion performance than do control subjects can be interpreted in two different ways. First, the processes that support object priming in amnesics may be impaired. Second, priming may be intact in amnesics, but normal subjects supplement completion test performance by engaging in explicit retrieval strategies (e.g., Milner *et al.*, 1968). The same sort of interpretive problem arises when an experimental variable has parallel effects on explicit and implicit tests. The parallel pattern of results may on the one hand reflect an important similarity between implicit and explicit memory; on the other hand, it may be attributable to the use of explicit retrieval strategies on a nominally implicit test.

In a general discussion of the issue, Schacter, Bowers, and Booker (1989) put forward a method for dealing with this problem, alluded to earlier in the article, called the *retrieval intentionality criterion*. This criterion consists of three key components: (1) the same nominal cues should be presented to subjects on implicit and explicit tests; (2) only the implicit/explicit nature of test instructions should be varied; and (3) an experimental or subject variable should be identified that produces dissociations between implicit and explicit task performance. Schacter *et al.* argued that when an implicit/explicit dissociation is observed under these conditions, the possibility that subjects use explicit strategies on the implicit test can be ruled out. Adherence to this criterion provides a noncircular means for interpreting parallel effects on implicit and explicit tasks. If parallel effects of experimental variables A and B are observed within the same paradigm that also produces a dissociation between variables C and D, then we can be confident that the observed parallel effects are not attributable to explicit memory processes (see Schacter *et al.*, 1989, for more extensive discussion).

Applying this logic to the research that we have reviewed, only a few studies have produced dissociations in strict conformity with the retrieval intentionality criterion (Gabrielli *et al.*, in press; Kunst-Wilson & Zajonc, 1980; Mandler *et al.*, 1987; Mitchell, 1989; Musen & Treisman, 1990; Parkin & Streete, 1988; Schacter *et al.*, 1990; Schacter & Bowers, in preparation; Schacter & Merikle, in preparation). Several studies have documented similar dissociations under conditions in which the nominal cues differed on implicit and explicit tests (e.g., Hirshman *et al.*, in press; Jacoby *et al.*, 1989; Weldon & Roediger, 1987; Winnick & Daniel, 1970);

as discussed previously, this sort of comparison is not entirely satisfactory. Other investigations have attempted to examine the contribution of explicit memory processes to priming through different types of analyses (e.g., Snodgrass & Feenan, 1989; Warren & Morton, 1982). Unfortunately, however, a large number of studies on priming of nonverbal information have not included explicit memory tests. Therefore, we must remain uncertain about the possible role of explicit remembering in many of the phenomena reviewed earlier. Until appropriate dissociations are produced, interpretive caution should be exercised when attempting to draw theoretical inferences from priming studies about the processes and systems involved in implicit and explicit memory.

B. Facilitation of Naming versus Priming of Nonverbal Information

A second issue with important interpretive implications that has been acknowledged in the literature concerns the role of object naming in priming effects. The question is whether we can safely attribute observed performance facilitations to priming of *nonverbal* information—representations of objects, patterns, faces, and the like—or whether these effects are attributable to overt or covert naming processes. As discussed by several investigators (e.g., Bruce & Valentine, 1985; Lachman & Lachman, 1980), subjects may generate names of familiar objects at the time of study, and facilitated access to object names may produce priming on subsequent tests. And even when unfamiliar objects or patterns are used, it is always possible that subjects code them verbally during study and that priming is attributable to retrieval of verbal codes at test.

One reason why this issue must be considered seriously is that most of the implicit tests that have been used to assess priming of nonverbal information involve a naming response; identification of fragmented or briefly presented pictures and picture naming are the most prominent examples. One type of evidence relevant to this issue is that studying words yields little if any priming on picture completion and identification tests (Warren & Morton, 1982; Weldon & Roediger, 1987) and reduced (relative to pictures) though significant priming on picture-naming tests (Durso & Johnson, 1979; Lachman & Lachman, 1980). These results suggest that simple generation of a verbal label is not a major source of priming on nonverbal tests. On the other hand, naming a word during the study phase has produced some priming in several studies, thereby suggesting that name generation may play some role in priming on picture identification and naming tests. Moreover, even if naming a *word* at the time of study produced no priming, it is still logically possible that priming depends crucially on generating a name for a studied *picture*. Lachman and Lachman (1980) attempted to exclude this possibility by demonstrating that presentation of lure pictures on a yes/no recognition test produced significant facilitation on a subsequent picture-naming test. However, the theoretical significance of this finding depends critically on the validity of the rather uncertain assumption that subjects do not generate an object name when making a recognition decision about a lure item. Bruce and Valentine (1985) found that naming a face produced priming on a subsequent face-naming task but not on a semantic decision task, thereby suggesting that naming processes may play a role on some though not all implicit tests.

Several additional findings call into question the importance of object naming during the study phase for subsequent priming. First, priming is higher when the *same* object is presented at study and test than when a *different* object with the same name is presented (Bartram, 1974; Biederman & Cooper, 1989b; Jacoby *et al.*, 1989; Schacter & Bowers, in preparation; Warren & Morton, 1982). Second, the specific *orientation* of an object at study and test appears to influence priming, at least under some conditions (Bartram, 1974; Jolicouer, 1985; Jolicoeur & Milliken, 1989). These findings suggest that priming depends on specific visual attributes of encoded objects and cannot be explained as a simple consequence of generating an object name at the time of study. However, with the exception of the Schacter and Bowers study, these experiments have not produced implicit/explicit dissociations in conformity with the retrieval intentionality criterion discussed in the preceding section. Until appropriate dissociations are produced in these paradigms, it could be argued that the observed specificity effects reflect the use of explicit memory processes and thus may not speak directly to the role of naming processes in priming.

A third kind of evidence is provided by the finding of robust priming for novel objects and patterns that do not have any names, under conditions in which observed implicit/explicit dissociations rule out the possibility that priming is attributable to explicit memory (Gabrielli *et al.*, in press; Kunst-Wilson & Zajonc, 1980; Mandler *et al.*, 1987; Musen & Treisman, 1990; Schacter *et al.*, 1990). Of course, it could be argued that even though novel objects and patterns do not have agreed-upon names, subjects may attempt to code them verbally anyway and that it is this verbal coding that supports priming. Existing evidence, however, casts doubt on this possibility: Priming of novel shapes has been observed under conditions of brief exposure at which subjects do not reliably detect the presence of the shapes (Kunst-Wilson & Zajonc, 1980), and when subjects were *required* to generate verbal labels for unfamiliar objects in the study by Schacter *et al.* (1990, Experiment 2), no priming was observed on a subsequent object decision test. A fourth and related source of evidence is provided by the finding of robust priming on fragment completion (Schacter & Merikle, in preparation) and object identification (Schacter & Bowers, in preparation) tasks following a vertex-counting encoding task in which subjects did not overtly name target objects.

In summary, although the role of naming and verbal labeling in priming of allegedly nonverbal information clearly requires more extensive study, at least two tentative conclusions can be advanced. First, when implicit tests are used that require a naming response, prior naming may contribute to priming. Second, there are good reasons to believe that priming of nonverbal information on implicit tests that do not require a naming response (e.g., object decision, semantic decision, preference, dot-pattern identification, and completion) is independent of prior naming. Accordingly, we suggest that progress in understanding priming of nonverbal information will be facilitated by development of implicit tests that do not require naming responses.

C. Theoretical Accounts

The literature that we have reviewed encompasses a number of theoretical issues and problems that reflect the concerns of the various contributors to it: Some investigators have been concerned primarily with the nature of semantic memory processes; others have attempted to use priming as a tool to investigate the structure of object representations; and still others have focused on the nature of the processes and systems that underlie implicit and explicit memory. Thus, for example, one of the key issues that has motivated a number of studies of picture–word transfer concerns whether pictures and words share a common, amodal representation or whether there are separate, form-based representations for the two types of materials (e.g., Durso & Johnson, 1979; Kirsner *et al.*, 1986; Kroll & Potter, 1984; Lachman & Lachman, 1980). The fact that modest and sometimes negligible amounts of priming are observed between pictures and words supports the idea that separate form-based representations exist. As noted earlier, however, high levels of picture–word transfer in *semantic* priming paradigms suggest the existence of an amodal level of semantic representation that is distinct from modality-specific form-based representations (for discussion, see Kirsner *et al.*, 1986; Riddoch & Humphreys, 1987; Snodgrass, 1984; Vanderwart, 1984). Thus, any attempt to explain repetition priming of nonverbal information in terms of semantic processes is unlikely to succeed.

An early theoretical account of picture priming was offered by Warren and Morton (1982), who argued that priming of familiar objects reflects the temporary activation of a preexisting representation of the object that they called a *pictogen*. A pictogen was held to be an abstract representation of all objects with the same name (e.g., all clocks). Thus, the pictogen is a sort of nonverbal equivalent of the *logogen*, a term coined by Morton (1979) to refer to abstract lexical representations that are presumed to underlie word priming effects. The data that we have reviewed, however, present several problems for the pictogen view: Priming of nonverbal information can last for days and weeks whereas activation of a pictogen was held to decay extremely rapidly; priming has been demonstrated for novel objects and patterns that have no preexisting pictogens; and some priming effects appear to be more specific than would be expected if they were based on activation of an abstract pictogen. Thus, just as logogen theory has serious problems handling the data from verbal priming experiments (e.g., Jacoby, 1983; Richardson-Klavehn & Bjork, 1988; Roediger & Blaxton, 1987; Schacter, 1987, in press), the pictogen view cannot account for all of the data on nonverbal priming.

In contrast to the pictogen view, Weldon and Roediger (1987) and Jacoby *et al.* (1989) have proposed an episodic account of priming that they have applied to nonverbal materials. By their view, implicit memory can be understood by applying principles that have proven useful in understanding explicit memory, such as transfer-appropriate processing and encoding specificity. More specifically, they have argued that performance on such tests as picture identification and completion is primarily *data driven*—that is, guided by physical features of test cues. Consistent with the principle of transfer appropriate processing (e.g., Roediger & Blaxton, 1987), it is thus argued that priming on these tasks depends on access to episodic representations of specific physical features of target materials. Performance on standard explicit tests of recall and recognition, in contrast, typically depends on subject-initiated, *conceptually driven* processing. This view can thus accommodate the general finding of a large form-based component in object priming, is consistent with observed specificity effects, handles a number of implicit/explicit dissociations, and is not embarrassed by instances of long-lasting priming. One serious problem with this view, however, is that it does not provide an account of preserved priming of either words or nonverbal materials in amnesic patients (for discussion, see Hayman & Tulving, 1989; Schacter, in press).

D. Priming and Perceptual Representation Systems

An alternative approach that incorporates some of the foregoing ideas and extends them into a multiple memory systems framework has been described in detail in several recent papers (Schacter, in press; Schacter *et al.*, 1990; Tulving & Schacter, 1990). The basic idea is that priming on data-driven implicit tests depends on a class of presemantic *perceptual representation systems* that are dedicated to the representation and retrieval of information about the form and structure, but not the meaning, of words and objects. This general notion is motivated by two independent lines of evidence. The first is provided by priming experiments. Several studies of object priming reviewed in this article (e.g., Carroll *et al.*, 1985; Schacter *et al.*, in press; Schacter & Bowers, in preparation; Schacter & Merikle, in preparation), as well as various studies of verbal priming (e.g., Graf & Mandler, 1984; Jacoby & Dallas, 1981; Schacter & McGlynn, 1989), have shown that priming effects are robust following structural encoding tasks and do not require any semantic study processing. In addition, a number of studies have shown that priming is sensitive to changes in structural or surface feature information (e.g., Bartram, 1974; Jacoby *et al.*, 1989; Schacter & Bowers, in preparation; Weldon & Roediger, 1987). Thus, experimental evidence from implicit memory studies indicates that priming on data-driven tests such as completion and identification is a structurally based, presemantic phenomenon.

Second, neuropsychological research on patients with selective deficits of reading and object processing has provided evidence for presemantic perceptual systems. The crucial observations take the form of striking dissociations between impaired access to semantic knowledge of words or objects on the one hand together with relatively intact access to structural knowledge on the other (e.g., Ellis & Young, 1988). In the verbal domain, for example, several studies have demonstrated intact access to visual and orthographic knowledge of words despite impaired acccess to word meaning (e.g., Funnell, 1983; Schwartz, Marin, & Saffran, 1979). These studies, together with converging evidence from neuroimaging research using the technique of positron emission tomography (Petersen, Fox, Posner, Mintum, & Raichle, 1988), point to the existence of a presemantic *visual word-form system* (Warrington Shallice, 1980) that appears to be involved in various verbal priming effects (Schacter, in press).

More directly relevant to the present concerns, other neuropsychological research suggests the existence of a presemantic system that is dedicated to handling information about the form and structure of visual objects. The key evidence comes from studies of patients with various forms of object agnosia, who are typically unable to recognize common objects. A number of studies have shown that such patients perform relatively well on tests that tap *structural* knowledge of objects despite severe impairments on tests that tap *associative* or *functional* knowledge of the

same objects (cf. Riddoch & Humphreys, 1987; Sartori & Job, 1988; Warrington, 1982; Warrington & Taylor, 1978). Following Riddoch and Humphreys (1987), we refer to this system as the *structural description system* (Schacter *et al.*, 1990).

In view of the aforementioned evidence that various nonverbal priming effects are observed independently of semantic study processing and are affected by study–test changes in the physical form and structure of target materials, we suggest that the structural description system plays an important role in priming of nonverbal information. Because this system is hypothesized to operate exclusively on the form and structure of objects and does not handle associative, functional, or contextual information about them, we think that it plays a limited role in explicit memory for a previous encounter with an object. Explicit remembering appears to require the involvement of an episodic memory system (Tulving, 1983) that represents various kinds of information about the content of an event and relates them to a spatiotemporal context.

The idea that a presemantic structural description system plays an important role in implicit memory for nonverbal information represents a beginning hypothesis that requires a good deal of further development. For example, the extent to which this system is involved in priming will likely depend on the exact nature of the implicit memory test that is used. Though we think that the structural description system is involved in nonverbal priming when data-driven implicit tests are used, different processes will likely be tapped when conceptually driven tests are used (see Schacter, in press; Tulving & Schacter, 1990). Similarly, more detailed hypotheses are required concerning exactly what types of information the system handles and how they are expressed on implicit memory tests. Despite these and other gaps in the framework, this idea has the virtue of specifying a candidate system that is involved in nonverbal priming and suggesting an underlying structural basis for transfer-appropriate processing models. At the same time, it also provides an explicit link between implicit memory research and neuropsychological studies of reading and object-processing deficits that can help to guide future studies concerned with priming of nonverbal information and the nature of implicit memory.

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Priming and recognition of transformed three-dimensional objects: Effects of size and reflection

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Abstract

Two experiments explore the nature of the mental representations of unfamiliar, three-dimensional objects underlying performance on implicit and explicit tests of memory. In both experiments, subjects studied depictions of objects under conditions designed to encourage the encoding of global structure. Implicit memory was assessed by an object decision task, in which briefly presented drawings of test objects were classified as to their structural possibility or impossibility. Explicit memory was assessed by a surprise recognition test. The principal experimental manipulation was the relationship between the sizes (Experiment 1) or the left/right parities (Experiment 2) of the studied and tested objects. In both experiments, priming of performance on the object decision task was observed; and, priming remained substantial despite study-to-test transformations of size or reflection. Recognition memory, in contrast, was significantly impaired by both the size and reflection transformations. These results support the notion that distinct representational systems mediate priming and recognition -- a pre-semantic structural description system that constructs representations of objects invariant over size and reflection, and an episodic system that encodes these transformations as properties of an object's distinctive representation in memory.

A phenomenon of considerable theoretical importance and vigorous experimental investigation is the dissociation between performance on explicit and implicit tests of memory. Explicit tests typically require conscious recall or recognition of previously presented material, while on implicit tests the effects of such material are demonstrated without requiring the conscious recollection of a specific study episode (e.g., Graf & Schacter, 1985; Schacter, 1987). Implicit effects are generally inferred from performance facilitation in the form of priming, in which the beneficial influence of exposure to a particular stimulus is manifested in the absence of explicit instructions to remember the stimulus (e.g., Cofer, 1967; Tulving & Schacter, 1990). One source of evidence for the dissociation between implicit and explicit forms of remembering comes from laboratory studies with intact, adult subjects, in which a variety of experimental manipulations produce differential or even opposite effects on performance on implicit and explicit tasks (for reviews, see Richardson-Klavehn & Bjork, 1988; Schacter, 1987). Another source of evidence comes from reports of essentially normal priming effects in amnesic patients who exhibit severely impaired explicit memory (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985; Gabrieli, Milberg, Keane, & Corkin, 1990; Graf, Squire, & Mandler, 1984; Jacoby & Witherspoon, 1982; Moscovitch, 1982; Schacter, 1985; Schacter & Graf, 1986; Shimamura & Squire, 1984; Warrington & Weiskrantz, 1968, 1974; for a review, see Shimamura, 1986).

Two primary theoretical interpretations of dissociations between performance on implicit and explicit memory tasks and of priming effects themselves have been advanced. One view, which we favor, holds that dissociations between priming and performance on explicit tasks reveal the operation of separable underlying memory systems (cf., Gabrieli et al., 1990; Hayman & Tulving, 1989; Squire, 1987; Schacter, 1987). In particular, Schacter and his associates (Schacter, 1990; Schacter et al., 1990a, 1990b; Tulving & Schacter, 1990) have proposed that priming on implicit tests of memory is mediated by a pre-semantic perceptual representation system. An alternative, though not mutually exclusive, theoretical account holds that dissociations between priming and explicit memory are attributable to different processes operating within a single memory system (e.g., Jacoby, 1983; Mandler, 1985, 1988; Roediger, Weldon, & Challis, 1989).

One version of this latter account proposes that the principle of transfer-appropriate processing (Morris, Bransford, & Franks, 1977) can serve as a basis for understanding dissociations between performance on implicit and explicit tasks (e.g., Roediger & Blaxton, 1987; Roediger et al., 1989). The general idea is that performance on a memory test is related to the degree to which the processing operations by which an item was initially encoded are reinstated at the time of test; and, most implicit tests of memory rely strongly on perceptual processing while explicit tests require more semantic or conceptual processing. Evidence supporting this proposal comes from the reported specificity of priming effects to conditions in which the modality and other surface characteristics of study and test items are congruent (e.g., Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981; Roediger & Blaxton, 1987).

While most of the research on dissociations between implicit and explicit tests of memory have used verbal materials as stimuli, a number of studies of priming of familiar and unfamiliar nonverbal stimuli have recently been reported (e.g., Bentin & Moscovitch, 1988; Biederman & Cooper, 1990, in press, a, in press, b; Durso & Johnson, 1979; Gabrieli et al., 1990; Jacoby, Baker, & Brooks, 1989; Kersteen-Tucker, 1991; Kroll & Potter, 1984; Mitchell & Brown, 1988; Musen & Treisman, 1990; Warrington & Weiskrantz, 1968; Weldon & Roediger, 1987; for a review, see Schacter, Delaney, & Merikle, 1990). Of particular relevance to the present experiments are a series of studies described by Schacter, Cooper, & Delaney (1990a) and Schacter, Cooper, Delaney, Peterson, & Tharan (1991). The stimuli in these experiments were line drawings of unfamiliar, three-dimensional objects. While all of the drawings depicted novel, meaningless objects that did not have pre-existing representations in memory, only half of the objects were possible -- in the sense of corresponding to structures whose surfaces were arranged such that they could exist in the three-dimensional world. The other half of the drawings depicted impossible structures whose surfaces and edges contained local violations and ambiguities that made it impossible for them to exist as actual three-dimensional objects (cf., Draper, 1978; Penrose & Penrose, 1958).

The purpose of the Schacter et al. (1990a, 1991a) experiments was to assess the relationship between performance on implicit and explicit tests of memory for these unfamiliar, three-dimensional objects, as a function of a variety of different conditions of encoding. Explicit memory was evaluated by performance on a standard "yes/no" recognition test; implicit memory was assessed by performance on a version of an object decision task (cf., Kroll & Potter, 1984). Specifically, following study of half of the objects, subjects were required to indicate whether individual objects presented for 100 ms were possible or impossible. Facilitation of performance on previously studied -- compared with nonstudied -- objects constitutes evidence for implicit memory or priming on this object decision task.

Several key findings reported by Schacter et al. (1990a; 1991a) are directly relevant to the present experiments. First, significant priming was obtained on the object decision task, but only following study tasks that required the encoding of information about the global three-dimensional structure of individual objects. The "structural" encoding task that produced the most robust object decision priming required subjects to determine whether each object presented for study faced primarily to the left or to the right. Study conditions involving semantic or elaborative analysis (i.e., requiring subjects to think of a familiar object that each depicted structure reminded them of), as well as conditions involving the encoding of local visual features (i.e., requiring subjects to determine whether each drawing contained more horizontal than vertical lines), failed to produce any significant priming of performance on the object decision task. Second, priming -- when observed -- was always confined to structurally possible versions of the test objects. Priming for impossibile objects was not observed under any conditions, despite modifications of instructions emphasizing "impossible" over "possible" responses, minor changes in the nature of the stimulus materials, and manipulations of the number, quality, and duration of exposures to items on the study list (Schacter et al., 1991a). Finally, marked dissociations between performance on implicit (object decision) and explicit (recognition) tests of memory for these unfamiliar, three-dimensional objects were obtained. Study manipulations designed to enhance the distinctiveness of an object's encoding in memory (e.g., requiring semantic elaboration of each studied object, Schacter et al., 1990a, Experiment 2; repeating presentation of objects on the study list tour times, Schacter et al., 1991a, Experiment 1) produced significant enhancement of recognition performance, but either no priming or no change in the magnitude of priming compared with a single-exposure study condition.

The pattern of results summarized above led Schacter et al. (1990a, 1990b; Schacter et al., 1991a) to argue that priming on the object decision task is supported by a mental representation of the three-dimensional relations that define the structure of an object. Furthermore, the memory system that encodes and represents this structural description of an object is functionally separable trom the episodic system that supports performance on explicit tests of memory. This latter system is supported by various sources of information about object properties -- including semantic, associative, and functional information -- as well as information about local visual features. The structural description system (cf., Riddoch & Humphreys, 1987), in contrast, is pre-semantic, specialized for representing global information about visual form and object structure, and part of a more general perceptual representation system (Schacter, 1990; Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990).

This theoretical framework provides a coherent account of the central findings from the Schacter et al. (1990a; Schacter et al.,1991a) experiments described above. In particular, the hypothesis of a separable structural description system is consistent with the Schacter et al. (1990a) findings that (a) priming on the object decision task was only obtained following study tasks requiring structural (left/right) encoding, and (b) priming of judgments of impossibility was never observed. Presumably, this latter finding reflects computational constraints on the structural description system; impossible objects, by definition, cannot be modeled by an internal representation of global relations among components of objects in the three-dimensional world (cf., Schacter et al., 1991a). Finally, we have also found that brain-damaged patients with episodic memory deficits show intact priming on the object decision task (Schacter, Cooper, Tharan, & Rubens, 1991).

Converging evidence for a system for the representation of information about global structural relations -- that is distinct from the representational system for semantic, associative information -- comes from research in cognitive and clinical neuropsychology on forms of visual object agnosia (for a review, see Farah, 1990). Most suggestive from the present perspective are reports of patients with intact access to knowledge about the structure of objects, but with serious impairment in access to information about their semantic and functional properties (e.g., Riddoch & Humphreys, 1987; Warrington, 1982; Warrington & Taylor, 1978). Other patients apparently exhibit a complementary pattern of selective deficits, with impairment in the specific ability to represent the global structure of visual objects (e.g., Ratcliff & Newcombe, 1982). The similarity of these reports to the pattern of laboratory-induced dissociations between access to structural and semantic representations of visual objects (Schacter et al., 1990a; Schacter et al., 1991a) provides converging support for the notion of a system for the representation of structural descriptions of objects, underlying priming on the object decision task, that is distinct from the eposidic system mediating explicit recognition.

The aim of the experiments reported here is to explore in more detail the nature of the proposed structural description system. In so doing, we seek to unite theoretical issues and experimental techniques in the area of memory with general considerations about the processes and representations underlying object perception and recognition. Like others (e.g., Biederman, 1987; Marr, 1982; Marr & Nishihara, 1978; Palmer, 1975; Reed, 1974; Sutherland, 1973), we view the computation of a representation of the structural relations among components of an object as a primary function of higher-level vision. Our objective is to pose questions about the nature of the information embodied in such structural descriptions of objects that may be investigated independently of questions concerning the precise characterization of the components or primitive units, e.g., elementary visual features (Sutherland, 1968), generalized cones (Marr, 1982; Marr & Nishihara, 1978), or geons (Biederman, 1987), among which structural relations are computed.

Our general research strategy uses the experimental paradigm introduced by Schacter et al. (1990a) as a tool for exploring the nature of the information embodied in structural description representations -- hypothesized to mediate object decision priming -- of unfamiliar, three-dimensional objects. One simplified view of the nature of such structural descriptions might hold that only information concerning relations among component units is preserved in the underlying mental representations. Under this view, it would follow that aspects of visual information irrelevant to the coding of such global relations among components should not be represented in or accessible from structural descriptions of objects. If, by hypothesis, structural description representations of this kind support priming on the object decision task, then variation in information concerning properties like object size or overall reflectance -- which do not contribute to the representation of global structure -- should be unrelated to performance on the object decision task. Variation in other forms of information that might serve to enhance or to reveal certain relations while obscuring others (e.g., occlusion of intersections, depicted three-dimensional orientation), could contribute to the representation of global structure and, as a consequence, affect object decision performance.

The experiments reported below were designed to examine whether certain forms of information are preserved in structural representations of objects by asking whether study-to-test changes in those types of information affect object decision, compared with explicit recognition, performance. The logic of our experimental approach is as follows: To the extent that study-to-test changes eliminate or significantly reduce the magnitude of obtained priming or recognition effects, we can conclude that the representational system accessed by the relevant memory task *does preserve* the type of information being changed. However, if obtained priming or recognition effects persist despite study-to-test changes in certain forms of information about objects, then we can conclude that the representational system being accessed by the relevant memory test *is not sensitive to* the type of information undergoing change. In Experiment 1, the effects of introducing study-to-test changes in object size on implicit and explicit tests of memory are assessed. Experiment 2 examines the effects of overall reflection on both object decision and recognition tasks.

Experiment 1

Retinal size is a characteristic property of an object that is useful for recognition. In particular, differences in the absolute sizes of objects viewed at the same distance might function as an important source of information for discriminating among them. However, there is little reason to expect on logical grounds that size should be a property encoded in the structural description of an object. Indeed, if a structural description represents only global relations among the components of an object, then invariance over changing retinal size should enhance the generality of such representations. One source of evidence consistent with these logical considerations comes from studies of the neuroanotomical basis of visual object processing (for a recent review and discussion, see Plaut & Farah, 1990). Both behavioral evidence from monkeys with localized lesions (e.g., Ungerleider, Ganz, & Pribram, 1969) and electrophysiological evidence from the response properties of single cells (e.g., Desimone, Albright, Gross, & Bruce, 1984; Perrett, Rolls, & Caan, 1982; Perrett, Smith, Potter, Mistlin, Head, Milner, & Jeeves, 1985; Rolls & Baylis, 1986; Sato, Kawamura, & Iwai, 1980; Schwartz, Desimone, Albright, & Gross, 1983) indicate that regions of the inferior temporal cortex play a central role in the size-invariant representation of the structure or shape of visual objects.

Accordingly, we reasoned that size would most likely *not* be represented in the structural description of an unfamiliar, three-dimensional object. Thus, we predicted that priming on the "possible/impossible" object decision task should be relatively unaffected by study-to-test variations in size. In contrast, we expected explicit recognition to suffer as a result of the size manipulation. This is because size seems to be a characteristic property that could enhance the distinctiveness of an object's representation in memory; hence, it is likely to be a useful form of information for the episodic system to encode. Consistent with this idea, research by other investigators (e.g., Jolicoeur, 1987; Jolicoeur & Besner, 1987) provides an empirical basis for predicting that study-to-test changes in the size of target objects should impair recognition performance.

Method

Subjects. The 96 subjects were undergraduate students at Columbia University who participated in the experiment for either course credit or payment of $5.00. Subjects were randomly assigned to the experimental conditions described below.

Stimuli. The experimental materials were line drawings of 40 unfamiliar, three-dimensional objects similar to those displayed in Figure 1. Twenty of the objects were possible, in that they depicted structures that could exist in the three-dimensional world. Twenty of the objects were impossible, in that they contained edge and surface ambiguities resulting in structures that could not physically exist as three-dimensional objects. Eighteen of the 20 possible objects were taken from the set of materials described and used in the experiments reported by Schacter et al., 1990a. The remaining 2 possible objects were drawn from the set used by Schacter et al., 1991a. (This substitution was necessary because 2 of the 20 objects originally used by Schacter et al., 1990a, contained curved contours; curves are difficult to render on the computer graphics system used to display the stimuli in the present experiment.) All 20 of the impossible objects were taken from the materials used by Schacter et al., 1991a. It should be noted that all stimuli had previously met the following criteria for inclusion in the experimental set (described more fully in Schacter et al., 1990a; Schacter et al., 1991a): (a) Average inter-subject agreement as to the objects' possibility or impossibility was 95% or greater in a pilot study using unlimited exposure durations, and (b) Baseline performance from an independent group of subjects for determining whether each object was "possible" or "impossible", when displayed for 100 ms, was on average approximately 65%.

An additional baseline study was done to aid in selecting the object sizes for the present experiment, and to ensure that absolute size was not systematically related to subjects' abilities to determine, in the absence of prior study, whether briefly exposed drawings depicted possible or impossible objects. Twenty students viewed balanced 10-item subsets of the 40 selected target objects (along with 10 practice objects, 5 possible and 5 impossible) at each of four sizes: 7.7, 11.5, 15.4, and 19.2 degrees of visual angle, at a viewing distance of approximately 50 cm. These sizes represent ratios of 1:1, 1:1.5, 1: 2, and 1: 2.5, moving from the smallest to the largest object set. The objects were displayed individually on the monitor of a Silicon Graphics Personal IRIS computer, and they appeared as white line drawings on a dark surround. Each 100-ms exposure of an object was preceded by an illuminated fixation cross in the center of the screen. Subjects were instructed to press the leftmost button on a mouse if they judged an object to be possible, and the rightmost button to indicate a judgment of impossibility. Baseline accuracy on this object decision task ranged from 60% to 80%, and performance was not systematically related to stimulus size. Consequently, the most extreme size ratio of 1: 2.5, corresponding to 7.7 ("small") and 19.2 ("large") degrees of visual angle, was selected for use in Experiment 1, in order to maximize sensitivity to effects of this variable. Within each size category, the 40 target objects were normalized for approximate size by scaling them to fit within a circular reference frame (cf., Schacter et al., 1991a, Experiment 4). The top half of Figure 1 displays a possible and an impossible object in sizes, the ratio of which corresponds to that between the large and the small sizes used in the present experiment.

Insert Figure 1 about here

Design. The design of the main experiment was a 2 (small vs. large encoded sizes) x 2 (small vs. large tested sizes) x 2 (object decision vs. recognition tasks) x 2 (possible vs. impossible object types) x 2 (studied vs. nonstudied objects) mixed factorial. The first three factors -- Studied Object Size, Tested Object Size, and Type of Memory Task -- were between-subjects variables. The last two factors -- Object Type and Item Type -- were manipulated within subjects. In addition, the 20 possible and 20 impossible target objects were randomly divided into two subsets, A and B, each containing 10 possible and 10 impossible objects. The two subsets were rotated through all experimental conditions, resulting in a completely counterbalanced design in which each subset appeared equally often as studied and nonstudied objects in each cell of the main design.

Procedure. Each of the 96 subjects was tested individually under incidental memory conditions. That is, subjects were initially told that the experiment concerned the perception of objects; they were not informed of the subsequent object decision or recognition task until shortly before it began. Only the "structural" encoding task employed by Schacter et al. (1990a, Experiments 1 and 2) and Schacter et al. (1991a) was used in all experimental conditions. Subjects were told that a series of line drawings would be presented, and that they were to indicate, for each, whether the depicted object appeared to be facing primarily to the left or to the right. Subjects were instructed to use the entire 5-sec exposure period to view each object carefully and make a considered left/right judgment. No mention was made of the possibility or impossibility of the objects at this point in the experiment. Five practice items were then presented, followed by presentation in a random order of 10 possible and 10 impossible objects. In this "study" phase, each object was presented centered on the screen for 5 sec. Subjects were instructed to press the rightmost mouse button if the object appeared to be facing to the right, and the leftmost mouse button if the object appeared to be facing to the left. Following initial presentation of the study list, each of the 20 objects was presented again, in a different random order. Half of the subjects studied objects defined as "small" (7.7 deg), and the other half of the subjects studied objects defined as "large" (19.2 deg).

Immediately after presentation of the study list and completion of the "left/right" judgments, subjects proceeded to the test phase of the experiment. Half of the subjects participated in the object decision task, and the other half participated in recognition.[1] Within each test task, half of the subjects from each (small vs. large size) encoding group viewed the test objects (half previously studied and half nonstudied) in the same size as presented during study; the other half of the subjects viewed the test objects in a size (small or large) changed from that presented during the left/right encoding task.

For the subjects who participated in the object decision task, instructions were administered that explained the difference between structurally possible and impossible objects, including some examples of both. Instructions emphasized the importance of looking at the fixation cross just prior to stimulus presentation, as well as the brief 100-ms duration of the test objects. Subjects were requested to press the rightmost button of the mouse if they judged an object to be possible, and the leftmost button if they determined that the object was impossible. Trials were self-paced, with each trial beginning when the subject depressed the middle mouse button. The object decision task began with presentation of10 practice trials, 5 displaying possible and 5 showing impossible objects. Immediately following practice, the 40 test objects were displayed individually. Twenty of the test trials consisted of possible structures, 20 of impossible ones. Within each possible or impossible drawing type, half of the objects were structures that had been viewed previously during the encoding phase, and half had not been seen before.

Subjects who participated in the surprise "yes/no" recognition task were informed that they would be presented with a series of objects, some of which had been shown during the previous left/right task and some of which were new. Subjects were told to indicate that an object had been presented before by pressing the rightmost button on the mouse, and to indicate that an object had not been shown previously by pressing the leftmost button. Instructions emphasized that the "yes/no" judgments were to be based solely on the shape of the test objects. Ten practice trials, 5 consisting of previously displayed practice items and 5 showing new items, were presented, followed by the 40 test trials. Half of these trials contained possible objects, half impossible objects, and within each object type, half of the drawings had been shown during the study phase and half had never been shown before. For each subject, the recognition trials were presented in a random order, and each object was displayed for a maximum of 5 sec, disappearing when the subject made the "yes/no" response.

At the completion of testing, all subjects were told the purpose of the experiment, and they were provided with a written description of the objectives and background of the program of research.

Results

The results of performance on the object decision task and the recognition task were analyzed and are described separately.

Object decision. Table 1 presents the central results for performance on the object decision task, expressed as proportion correct on the "possible/impossible" judgment, as a function of the main experimental variables -- size of encoded item, size of tested item, possible/impossible object type, and studied/nonstudied test item status.

Insert Table 1 about here

Several important features of these data should be noted. First, for possible objects presented in the same size at encoding and test (conditions SS and LL), there is substantial facilitation of object decision performance on studied items compared with nonstudied items. This is the usual priming effect (cf., Schacter et al., 1990a; Schacter et al., 1991a, 1991b) attributable to structural encoding. The data from the present experiment indicate that the magnitude of priming is not affected by the absolute (small or large) size of the studied and tested objects (.12 and .10, respectively). Second, when possible objects are studied and tested in *different* sizes (conditions SL and LS), priming of object decision judgments continues to be observed. Again, the magnitude of the effect does not depend strongly on the absolute sizes of the encoded and tested objects, and the amount of facilitation is even slightly greater when size relations at study and test are changed than when they remain the same (for condition SL, magnitude of priming = .19; for LS, priming = .15). Third, there is no evidence of facilitation of object decision performance on impossible objects in any of the experimental conditions.

Statistical analyses confirm this description of the central results. Two analyses of variance were performed on the object decision data -- one in which Encoded Size (small vs. large) and Tested Size (small vs. large) were treated as separate factors, and one collapsing over these factors, thus producing a single between-subjects factor of Size (same vs. changed from study to test) as well as the within-subject factors of Object Type (possible vs. impossible) and Item Type (studied vs. nonstudied). Since the outcomes of these ANOVAs are entirely consistent, only the second is reported. The main effect of (studied vs. nonstudied) Item Type was significant, $F(1,44) = 4.75$, $MSe = .018$, $p < .035$, as was the interaction between (studied vs. nonstudied) Item Type and (possible vs. impossible) Object Type, $F(1,44) = 26.20$, $MSe = .017$, $p < .0001$. Importantly, the main effect of (same vs. changed) Size did not approach statistical significance, $\underline{F}$ (1,44) < 1, nor did this factor enter into any significant interactions (all $\underline{F}$s < 1).[2]

It is worth noting that the data in Table 1 indicate the presence of "negative priming" for impossible objects, or the tendency to respond more correctly to nonstudied than to studied items. The presence of such "negative priming" raises the question of response bias in these data -- in particular, the possibility that priming observed for possible objects may reflect nothing more than a generalized tendency to respond "possible" to any object, possible or impossible, viewed at the time of initial encoding (for extensive discussion of this point, see Schacter et al., 1990a; Schacter et al., 1991a). Evidence against this possibility is provided by the significant main effect of studied vs. nonstudied objects, which indicates that the overall *accuracy* of object decision performance was increased by the study exposure.

To evaluate further the response bias issue, we conducted an analysis of the strength of association between the variables of Object Type (possible/impossible) and Responses ("possible"/"impossible") by computing the Yule Q statistic, a special case of the gamma correlation for analyzing association in 2 x 2 contingency tables (see Goodman & Kruskal, 1954; Hayman & Tulving, 1989; Nelson, 1984, 1990). Following the procedure recommended by Nelson (1984, 1990) and Reynolds (1977), 2 x 2 contingency tables defined by the orthogonal combination of Object Type and Responses were created for each subject, and Q values were computed separately for studied and nonstudied items. The thrust of this analysis is to indicate the strength of association (ranging from +1 to -1) between subjects' responses and the actual (possible/impossible) type of object for each of the experimental conditions. To the extent that priming results from an increase in the accuracy of object decision performance as a consequence of study -- rather than from a general bias to respond "possible" to all studied items -- then the Q (or, stimulus-response association) value for studied items should be higher than the Q value for nonstudied items. For the present data, the Q for studied objects was .65, for nonstudied objects Q = .54; and, these Q values are significantly different, t (47) = 2.003, p < .048.

Recognition memory. Table 2 displays the central results for recognition -- expressed in terms of hits, false alarms, and a corrected recognition measure of hits minus false alarms -- as a function of the main experimental variables. These data differ quite clearly from the object decision data with respect to the effect of the size manipulation on accuracy of performance. Most importantly, changing the size of test objects from that initially viewed during encoding (conditions SL and LS) produced substantial impairment of recognition performance, compared to conditions in which the study-to-test size relation was preserved (SS and LL). As Table 2 illustrates, this outcome was obtained for both possible and impossible objects, and it is apparent in both the hit rate and hits minus false alarms measures of performance. As in the results for object decision performance, however, the absolute sizes of encoded and tested objects has little influence on recognition memory (i.e., condition SS vs. LL and condition SL vs. LS); rather, it is the *relation* between studied and tested object sizes that determines the level of recognition memory.

Insert Table 2 about here

Analyses of variance performed on the hit rates and on the hits minus false alarms corrected recognition measure yielded virtually identical outcomes, as did ANOVAs with Encoded Size (small vs. large) and Tested Size (small vs. large) treated as separate factors and with a single between-subjects factor of Size (same vs. changed from study to test). Thus, we report only the results of the hits minus false alarms ANOVA with Size (same vs. changed) as the between-subjects factor. The only effect in this analysis to achieve statistical significance was the main effect of (same vs. changed) Size, F (1, 44) = 6.45, MSe = .062, $p < .01$.

Discussion

Several features of the results of Experiment 1 merit special attention. Some replicate theoretically important findings from earlier work; others provide new evidence concerning the representation and retrieval of information about three-dimensional objects. First, significant priming of object decision performance was obtained for possible objects under conditions of structural (left/right) encoding. The analyses reported above indicate that this facilitation is not attributable solely to a bias to respond "possible" to previously studied items. Thus, we have replicated one of the central findings of the earlier studies of Schacter et al. (1990a, 1990b), and have provided yet another demonstration of implicit memory for unfamiliar, three-dimensional objects with no pre-existing representation in memory. Second, no priming of object decision judgments was exhibited for impossible objects under any of the experimental conditions. This replicates the results of Schacter et al. (1991a), and provides additional evidence for the notion that object decision priming, when obtained, is supported by a mental representation of the global structure and relations among components of an object. That is, priming is not observed for impossible objects because of an inability to represent impossibility at the level of global structure; rather, the computation of impossibility relies on the detection of local edge and surface inconsistencies. This conclusion corresponds well with Hochberg's (1968) finding of the difficulty that subjects experience in integrating successive views of impossible objects into global structures. Third, we have demonstrated a marked dissociation between performance on implicit (object decision) and explicit (recognition) tests of memory. The presence of this dissociation is consistent with the idea that separable memory systems mediate the two types of judgments (cf., Schacter, 1990; Tulving & Schacter, 1990).

The nature of the observed dissociation constitutes our most important experimental finding. Specifically, the variable of size relation between studied and tested objects failed to produce an effect on performance on the object decision task, but it produced a marked effect on the level of explicit recognition memory. The lefthand section of Figure 2 provides a graphic summary of the differential effects of the study-to-test size relation variable on performance on the implicit (object decision, top panel) and the explicit (recognition, bottom panel) memory tasks. The generally high level and invariance of priming on the object decision task, for both same and changed size relations, provide compelling evidence that the structural description representations that support facilitation of implicit memory for unfamiliar, three-dimensional objects do not incorporate information concerning retinal size. The representational system underlying recognition, however, does appear sensitive to size, in that changing the relationship between studied and tested object sizes produces a sharp decline in recognition performance.

Insert Figure 2 about here

These results and interpretations make good sense on logical grounds, and they correspond nicely to the findings of other investigators using experimental materials and tasks quite different from our own. Specifically, Biederman & Cooper (1990) have recently reported an invariance of priming effects over changes in object size. Their paradigm used a repetition priming procedure, pictures of familiar objects as stimuli, and latency for object naming as the principal and most sensitive dependent measure. The consistency of these investigators' results with those of the present Experiment 1 -- which used an implicit memory task arguably closer to the level of "perceptual" or "visual" representation than the name identification task of Biederman & Cooper (1990) -- lends strong support to the claim that the structural description representations underlying priming do not incorporate information concerning object size.

The recognition results displayed in Table 2 and Figure 2 (bottom panel, lefthand side) can also be related to the findings of other researchers. Jolicoeur (1987) has documented an impairment in recognition memory for drawings of unfamiliar objects under conditions of study-to-test size variation; and, in a recognition version of their object-naming experiment, Biederman & Cooper (1990) found that size change caused a deterioration in both speed and accuracy of recognition. Similarly, the general finding in the literature on "same-different" matching of objects differing in size (e.g., Bundesen & Larsen, 1975; Bundesen, Larsen, & Farrell, 1981; Larsen & Bundesen, 1978; Jolicoeur & Besner, 1987) is that time to make the comparison increases with increasing size discrepancy (for conflicting results, see, e.g., Kubovy & Podgorny, 1981). This body of evidence, then, corresponds well with our finding of recognition impairment following a transformation in the size of unfamiliar three-dimensional objects.

A final result of interest from Experiment 1 concerns the difference in the behavior of impossible objects in the implicit and the explicit memory tasks. As noted above, we failed to obtain object decision priming for impossible objects -- owing, we have argued (Schacter et al., 1991a), to computational constraints on the construction of structural descriptions of such objects -- but observed robust priming for possible objects. In the explicit recognition situation, however, the variable of size transformation had parallel effects on possible and impossible objects, with possible objects yielding overall higher levels of recognition. This finding reinforces our claim of a dissociation between the representational systems underlying performance on implicit and explicit memory tasks. That is, not only the variable of size change, but also the variable of object type, affects these indices of memory differentially. Apparently, the system supporting recognition is capable of constructing some sort of mental representation of an impossible object (perhaps a piecemeal set of features, cf., Hochberg, 1968), and this representation is coded with respect to size.

Experiment 2

Another salient property of an object is its overall parity, or left-right orientation in three-dimensional space. Experiment 2 explored the effects of manipulating this property on both object decision judgments and explicit recognition. As with the feature of size, there are logical and empirical grounds for suspecting that left-right orientation is not coded in the structural description representation of an object. If structural descriptions embody only information about global relations among components of objects, then such relations will remain invariant despite a transformation of overall reflection about the vertical axis. Research examining the discrimination abilities of monkeys with inferior temporal cortex lesions (e.g., Cowey & Gross, 1970; Gross, 1973; 1978; Gross, Lewis, & Plaiser, 1975) indicates that performance on mirror-image discriminations with visual patterns is not impaired following lesioning. Thus, inferior temporal cortex is implicated as a neural locus for the representation of information about object structure, independent of size and mirror-image reflection. On the basis of these logical considerations and suggestive experimental reports, we reasoned that facilitation of object decision performance should be observed, despite study-to-test changes in the left-right orientation of our unfamiliar, three-dimensional objects. If left-right orientation, like size, serves as a property that enhances the distinctiveness of an object's episodic representation in memory, then we should expect the study-to-test transformation of overall reflection to produce impairment of explicit recognition performance.

Method

Subjects. Sixty-four undergraduate students at Columbia University participated in the experiment for either course credit or payment of $5.00. Subjects were randomly assigned to the experimental conditions described below.

Stimuli. The stimulus set was composed of line drawings of 48 unfamiliar, three-dimensional objects similar to those displayed in Figure 1. Twenty-four of the drawings depicted possible three-dimensional objects, and the other 24 represented impossible structures. The entire set of drawings contained all 40 of the objects used in Experiment 1. Eight objects, 4 possible and 4 impossible, were added in order to increase the number of observations per cell of the experimental design to a level that would permit the stimulus transformation variable to be manipulated within, rather than between, subjects. The 4 additional possible objects were taken from the set used by Schacter et al. (1991a), and the 4 additional impossible objects came from the set used by Schacter et al. (1990a). All 48 objects met the joint criteria for inclusion in the stimulus set described in connection with Experiment 1.

During testing, the objects were displayed individually on the monitor of a Silicon Graphics Personal IRIS computer, and they appeared as white line drawings on a dark surround. Objects were normalized for approximate size by scaling them to fit within a circular reference frame (cf., Schacter et al., 1991a, Experiment 4). Average angular subtension of the objects was 8 deg at a viewing distance of approximately 50 cm. The panel at the bottom of Figure 1 shows a possible and an impossible object from the stimulus set, displayed in both "standard" and "reflected" versions.

Design. The design of the experiment was a 2 (standard vs. reflected test versions) x 2 (possible vs. impossible object types) x 2 (studied vs. nonstudied item types) x 2 (object decision vs. recognition memory tasks) mixed factorial. All factors except the last Test Task factor were within-subject variables. The 24 possible and 24 impossible objects were randomly assigned to one of two object groups. Each object group contained 12 possible and 12 impossible objects. Both object groups appeared equally often in the standard and the reflected versions, and as studied and nonstudied items.

Procedure. Each of the 64 subjects was tested individually under incidental memory conditions. The procedure was identical to that described for Experiment 1, except for the following key differences: In the present experiment, the overall left-right orientation of test objects was varied, rather than their sizes, as in Experiment 1. Since stimulus transformation was a within-subject factor in the present experiment, all subjects in all experimental conditions studied objects displayed in the arbitrarily-defined standard orientation. Half of the test objects were presented in the standard orientation, and half were presented as mirror images or reflected versions. Order of presentation of the test objects was random.

Results

As in Experiment 1, object decision data and recognition data were analyzed separately.

Object decision. Table 3 shows the central results for performance on the object decision task, expressed as proportion correct on the "possible/impossible" judgment, as a function of the main experimental variables. Note, first, that overall accuracy for possible objects is .13 higher for studied than for nonstudied items, indicating the presence of priming. For possible objects viewed in the standard orientation at both study and test, this priming effect is extremely large (.18). For possible objects presented as mirror images or reflected versions at the time of test, the magnitude of priming is decreased, but remains substantial (.10). Second, there is essentially no evidence of priming for impossible objects, regardless of the relationship between the versions presented for study and at test. When impossible objects are studied in the standard version and tested in the reflected orientation, accuracy is slightly (.02) higher for studied than for nonstudied items. For impossible objects displayed in the standard version at both study and test, some "negative priming" (.07) is exhibited. Combined across possible and impossible objects, the overall priming effects in the standard (.06) and refelected (.06) orientations are identical.

Insert Table 3 about here

An analysis of variance confirmed the pattern of results described above. The main effect of (studied vs. nonstudied) Item Type was significant, $\underline{F}$ (1,31) = 9.57, MSe = .02, $\underline{p}$ < .005, the main effect of (possible vs. impossible) Object Type was significant, $\underline{F}$ (1, 31) = 7.21, MSe = .05, $\underline{p}$ < .02, and the interaction of these two variables was statistically reliable, $\underline{F}$

(1, 31) = 11.10, MSe = .04, $p < .002$. In addition, the three-way interaction of Item Type x Object Type x (standard vs. reflected) Version was marginally significant, F (1, 31) = 5.06, MSe = .03, $p < .04$. Importantly, the main effect of (standard vs. reflected) Version did not achieve the level of significance, F (1,31) = 2.73, MSe = .03, $p < .11$, nor did this factor produce any significant two-way interactions with other factors (all Fs < 1).

As in Experiment 1, we assessed the potential contribution of a bias to respond "possible" to all studied objects, regardless of their actual possible or impossible type, to the priming results shown in Table 3. The fact that a significant main effect of studied vs. nonstudied items was observed indicates that the *accuracy* of object decision performance was facilitated by the study task. We also computed Yule's Q values -- measures of strength of association between the variables of Object Type (possible/impossible) and Subjects' Responses ("possible/impossible") -- separately for studied and for nonstudied items. For the data displayed in Table 3, the Q for studied items (.78) and the Q for nonstudied items (.66) are significantly different, t (31) = 3.13, $p < .004$, providing further evidence that study of objects increased the accuracy of object decision performance, rather than creating a bias to respond "possible" to previously viewed items.

Recognition memory. The principal results of the explicit recognition task are displayed in Table 4 -- expressed in terms of hits, false alarms, and a corrected recognition measure of hits minus false alarms -- as a function of the main experimental variables. Note, in particular, that recognition is impaired -- as assessed by each of the three performance measures -- when reflected versions of the objects viewed at study are presented at the time of test, as compared with the level of recognition exhibited when both studied and tested objects are presented in the standard left-right orientation. Furthermore, this pattern is apparent for both possible and impossible test objects.

Insert Table 4 about here

Two analyses of variance were conducted using hit rates and hits minus false alarms as the dependent variables. The two ANOVAs yielded virtually identical outcomes, both substantiating the patterns described above, so only the results of the second ANOVA are reported. The only two terms in the ANOVA to achieve statistical significance were the main effects of (standard vs. reflected) Version, $\underline{F}$ (1, 24) = 10.67, MSe = .07, $\underline{p}$ < .004, and of (possible vs. impossible) Object Type, $\underline{F}$ (1, 24) = 40.65, MSe = .03, $\underline{p}$ < .03.

Discussion

The results of Experiment 2, examining the effects of left-right reversal on object decision priming and explicit recognition, parallel quite nicely the study-to-test size variation findings from Experiment 1. While not as clear cut as the results of Experiment 1, all theoretically important outcomes of Experiment 2 are statistically reliable. The key findings can be summarized as follows: First, robust priming of object decision performance was obtained for possible, but not for impossible, objects. Second, priming for possible objects continued to be exhibited, though at a somewhat attenuated level, despite study-to-test variation in the left-right orientation of possible three-dimensional objects. Third, marked dissociations of the effects of the variables of object version (standard vs. reflected) and object type (possible vs. impossible) on priming and recognition were observed. The righthand sections of Figure 2 provide a convenient summary of these results. Note, in particular, that while priming is evident even for reflected versions of possible test objects (top panel), recognition performance (bottom panel) declines when study-to-test changes in left-right orientation are introduced. Furthermore, recognition impairment occurs for both possible and impossible test objects; the complementary facilitation of object decision performance is not obtained for impossible objects under any of the experimental conditions.

This pattern of results leads us to conclude that parity, or overall left-right orientation, like size, is not incorporated in the structural description representations of objects that mediate priming. However, the episodic system underlying explicit recognition does appear sensitive to the left-right orientation of these unfamiliar, three-dimensional objects. In addition, we again find evidence, as in Experiment 1, that the episodic system is able to generate and to access for purposes of retrieval representations of impossible objects. Our results for object decision performance correspond well to some aspects of the data recently reported by Biederman & Cooper (in press, b). Using stimulus materials and experimental procedures quite different from our own (described in the Discussion of Experiment 1), these investigators have found that repetition priming for naming briefly presented pictures of familiar objects is exhibited even when the test pictures are mirror images of the pictures displayed in the initial presentation. The explicit recognition measure used by Biederman & Cooper (in press, b) involved memory for the left-right orientation of initially-presented objects, rather than "old/new" recognition as in our procedure. We would expect that, had these investigators included a recognition measure like the "yes/no" discrimination in the present Experiment 2, they would have found, as we have, an impairment in recognition of reversed versions of the test pictures.

General Discussion

The central results of our experiments, described above, have implications for several key theoretical issues in the areas of object representation and memory. We briefly discuss three issues that these results address.

<u>The nature of structural description representations</u>. The results of Experiments 1 and 2 are entirely consistent with the idea, described in earlier papers (Schacter et. al., 1990a, 1990b; Schacter et al., 1991a, 1991b), that priming on the object decision task is supported by a system that encodes the global, three-dimensional structure and relations among components of unfamiliar visual objects. Results of previous experiments indicate that this structural description system cannot compute globally consistent representations of impossible structures (Schacter et al., 1991a), and the failure to observe priming of such objects in the present experiments confirms this idea. Furthermore, structural description representations appear to be constructed as a result of study tasks that require attention to global aspects of the organization of surfaces of objects (such as the left/right encoding task used in the present

experiments), but not from tasks that require elaboration or the attribution of meaning to unfamiliar objects (Schacter et al., 1990a, Experiment 2). The present experiments add to our characterization of the properties of structural descriptions by demonstrating that such representations are *abstract*, in the sense of being insensitive to or invariant over the size and the left-right orientation of objects.

We have speculated that regions of inferior temporal (IT) cortex might constitute the neuroanatomical locus of the structural description system that produces priming in our object decision task (Schacter et al., 1991b). Evidence from behavioral studies of animals with lesions in IT and from neurophysiological studies of the response properties of single units in this area, described above and reviewed in Plaut & Farah (1990), is clearly consistent with this proposal. Cells in IT appear to be sensitive to global, stable properties of objects -- such as shape -- but not selectively responsive to object attributes that change with minor variation in conditions of viewing. These are just the properties that should prove useful for a representational system dedicated to coding invariants of perceptual structure, like the structural description system that we have explored in the present experiments. (For further discussion of the relation between the structural description system and other, related pre-semantic subsystems of perceptual representation, see Schacter, 1990; Schacter et al., 1990a; Schacter et al., 1991a, 1991b; Tulving & Schacter, 1990.)

An important question remaining for further research concerns what properties of the representation of objects the structural description system *does* incorporate, as well as which properties, in addition to size and parity, structural descriptions *are invariant with respect to*. If we take seriously the proposal that IT is the locus of the structural description system supporting object decision priming, then several tentative predictions (some of which we are in the process of testing) can be advanced. Representations of objects in IT appear to be abstracted over the properties of size, location, and to some extent picture-plane orientation, though the evidence is conflicting (see Holmes & Gross, 1984; Gross, 1978; for a review, Plaut & Farah, 1990). Thus, we would expect to observe priming on the object decision task, despite study-to-test changes in these object properties. Some evidence suggests that IT neurons are selective to texture and depicted three-dimensional orientation of objects (e.g., Desimone et al.,1984; Desimone, Schein, Moran, & Ungerleider, 1985; Perrett et al., 1985; Schwartz et al., 1983), as well as to global shape. We might expect that structural descriptions of objects represent these latter stimulus dimensions; hence, priming of object decision performance might not be exhibited following study-to-test transformations of such properties.

The nature of episodic representations of objects. An issue of considerable importance concerns the nature of the representations of unfamiliar, three-dimensional objects that underlie explicit recognition. Data from our present and previous experiments highlight a number of encoding, stimulus, and subject manipulations that produce marked effects on the level of explicit memory, while having little or no effect on object decision priming. Encoding or study-task conditions that produce enhancement of recognition performance include multiple exposures to the study list (Schacter et al., 1991a, Experiment 1), meaningful elaboration of the encoded objects (Schacter et al., 1990a Experiments 2 and 3), and encoding the list twice under different study instructions

(Schacter et al., 1991a, Experiment 3). Stimulus manipulations that reduce the level of explicit recognition include the size and reflection transformations introduced in the present Experiments 1 and 2. In addition, we consistently observe that overall recognition of impossible objects is lower than of possible objects, although both types of objects are affected by the experimental manipulations cited above in similar ways. Finally, subject manipulations of organic amnesia (Schacter et al., 1991b) and age (Schacter, Cooper, & Valdiserri, in preparation) impair recognition performance while sparing object decision priming.

These patterns of recognition performance have led us to conclude that explicit recognition of unfamiliar, three-dimensional objects involves the episodic memory system (Tulving, 1972, 1983). That is, episodic memory relies crucially on access to information about the distinctive spatial, temporal, contextual, and semantic aspects of objects that differentiate them from each other. Accordingly, any of these sources of information that are part of the conditions under which objects are encoded can be expected to enhance distinctiveness and, hence, the accessibility of the representation of an object to episodic retrieval processes. Any of these sources of distinctive information that are transformed from study to test (e.g., object size and left-right orientation, as in Experiments 1 and 2) can be expected to impair explicit recognition.

We view the information contained in structural descriptions of objects as just one among many sources of information used by the episodic system that underlies explicit recognition. A significant problem for future investigation concerns a clarification of the contribution of structural description representations to episodic recognition. At present, we can simply conclude, based on the data from Experiments 1 and 2, that size and left-right orientation are aspects of visual objects that are represented by the episodic system, but not by the structural description system.

The nature of underlying memory systems. We noted in the Introduction that much of the evidence demonstrating priming effects and dissociations between implicit and explicit tests of memory could be interpreted either as supporting the idea of multiple, separable underlying memory systems (e.g., Schacter, 1990; Schacter et al, 1990a; Schacter et al., 1991a, 1991b; Tulving & Schacter, 1990), or within the framework of transfer-appropriate processing (e.g., Roediger & Blaxton, 1987; Roediger et al., 1989). This latter approach views priming as the outcome of a reinstatement at the time of testing of the processing operations by which an item was initially encoded.

The data from Experiments 1 and 2, though not decisive, seem to us to be more compatibile with a multiple systems view than with the transfer-appropriate processing formulation. In particular, the finding that study-to-test changes in object size and left-right orientation produce robust priming of equal (Experiment 1) or substantial (Experiment 2) magnitude, when compared with conditions in which size and reflection relations remain constant from study to test, appears difficult to account for in a satisfying fashion by the principle of transfer-appropriate processing. That is, if similarity in processing operations at encoding and test are responsible for the existence of priming, then we should expect that changes in stimulus properties from study to test would undermine the similarity of processing operations and, thus, produce conditions unfavorable for the occurrence of priming on the object decision task. Indeed, advocates of transfer-appropriate processing have offered just this kind of analysis to account for observed effects of study-to-test changes in various kinds of surface information on implicit tasks such as fragment completion and perceptual identification (e.g., Roediger et al., 1989).

It is, of course, possible to modify the transfer-appropriate processing account to accomodate our findings by claiming that size and left-right orientation are not initially encoded by the processing operations active at the time of study. However, this modification then faces the serious problem of explaining why size and reflection variations *do* produce substantial effects on explicit recognition performance; and, if extended even further, this account becomes indistinguishable from our proposal of separate representational systems for information concerning global object structure (the structural description system) and information concerning distinctive visual, semantic, and contextual properties of objects (the episodic system). In short, we view the results of the present Experiments 1 and 2 -- along with demonstrations of stochastic independence between performance on implicit and explicit tests of memory (e.g., Hayman & Tulving, 1989; Musen & Treisman, 1990; Schacter et al., 1990a), and demonstrations of spared implicit memory with impaired explicit memory in amnesic patients (e.g., Schacter et al., 1991b) -- as lending strong support to the multiple systems formulation.

The results of Experiments 1 and 2 raise many questions in addition to those addressed above, and our interpretations leave many issues unresolved. In addition to further questions concerning forms of information represented in structural descriptions of objects, our results leave open the issue of what role, if any, structural description representations play in recognition and other high-level visual tasks (see

Cooper, 1988, 1989, 1990, in press, for discussion). Another important question concerns the possible relationship between the dissociable representational systems that we are examining and distinguishable processing subsystems proposed by other investigators (e.g., Kosslyn, 1987). Still another matter of interest concerns the generality of the present findings to other sets of experimental materials and other tests of implicit and explicit memory. All of these questions and issues are foci of attention in our ongoing program of research.

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Footnotes

1 In fact, both groups of subjects participated in both memory tasks, but in different orders, i.e., for one group, object decision followed by recognition, and for the other, recognition followed by object decision. However, performance on the second test task was not analyzed for either group of subjects, because second-task performance in the present experiment does not illuminate any substantive issues. In the case of object decision followed by recognition, the recognition test is simply a list discrimination task. In the case of recognition followed by object decision, the study-to-test object transformations have already been viewed during the recognition phase. Hence, the object decision task cannot provide an uncontaminated measure of priming of responses to transformed test stimuli.

2 Analyses of variance reported for both experiments were done on data from individual subjects, rather than from individual items. However, analyses computed over items confirmed the same central results as those obtained in the subject-based analyses.

Table 1

Object Decision Performance: Experiment 1

	Encoding/test relation					
	Same size			Changed size		
Item type	SS	LL	M	SL	LS	M
			Possible Objects			
Studied	.78	.75	.77	.77	.78	.77
Nonstudied	.66	.65	.65	.58	.63	.61
M	.72	.70		.68	.70	
			Impossible Objects			
Studied	.58	.73	.66	.73	.66	.70
Nonstudied	.66	.81	.73	.78	.68	.73
M	.62	.77		.75	.67	

Note. SS = studied in small size and tested in small size. LL = studied in large size and tested in large size. SL = studied in small size and tested in large size. LS = studied in large size and tested in small size.

Table 2

Recognition Performance: Experiment 1

	Encoding/test relation					
	Same size			Changed size		
Item type	SS	LL	M	SL	LS	M
	Possible Objects					
Studied	.78	.88	.83	.68	.66	.67
Nonstudied	.31	.13	.22	.23	.15	.19
Hits-FAs	.47	.76	.61	.46	.51	.48
	Impossible Objects					
Studied	.78	.82	.80	.66	.69	.68
Nonstudied	.26	.24	.25	.23	.26	.25
Hits-FAs	.52	.58	.55	.43	.43	.43

Note. Studied = proportion of studied items called "old" (hit rate). Nonstudied = proportion of nonstudied items called "old" (false alarm rate).

Table 3

Object Decision Performance: Experiment 2

	Encoding/test relation		
Item type	Standard	Reflected	M
	Possible Objects		
Studied	.89	.82	.85
Nonstudied	.71	.72	.72
M	.80	.77	
	Impossible Objects		
Studied	.70	.70	.70
Nonstudied	.77	.68	.72
M	.73	.69	

Table 4

Recognition Performance: Experiment 2

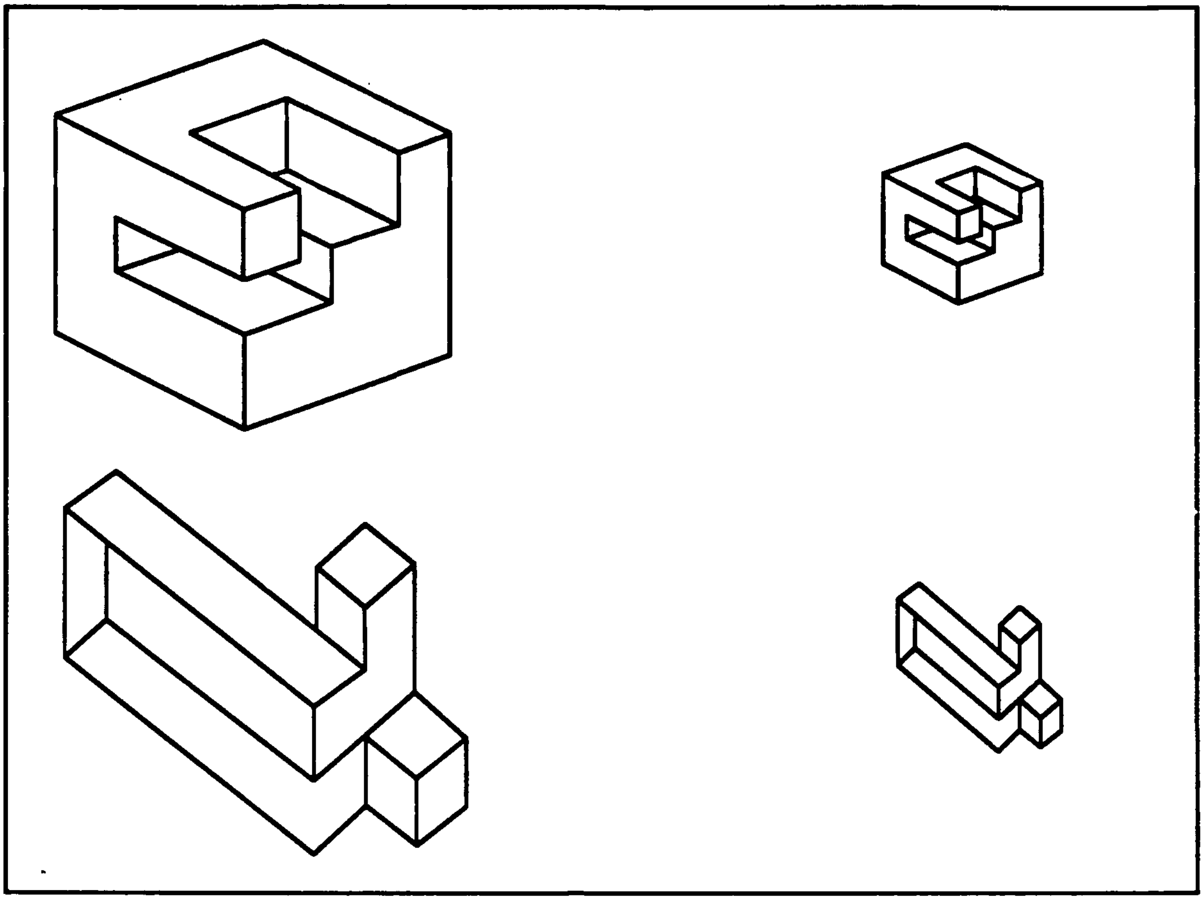
Item type	Encoding/test relation: Standard	Reflected	M
	Possible Objects		
Studied	.81	.77	.79
Nonstudied	.14	.18	.16
Hits-FAs	.67	.59	.63
	Impossible Objects		
Studied	.73	.58	.66
Nonstudied	.25	.29	.27
Hits-FAs	.48	.29	.39

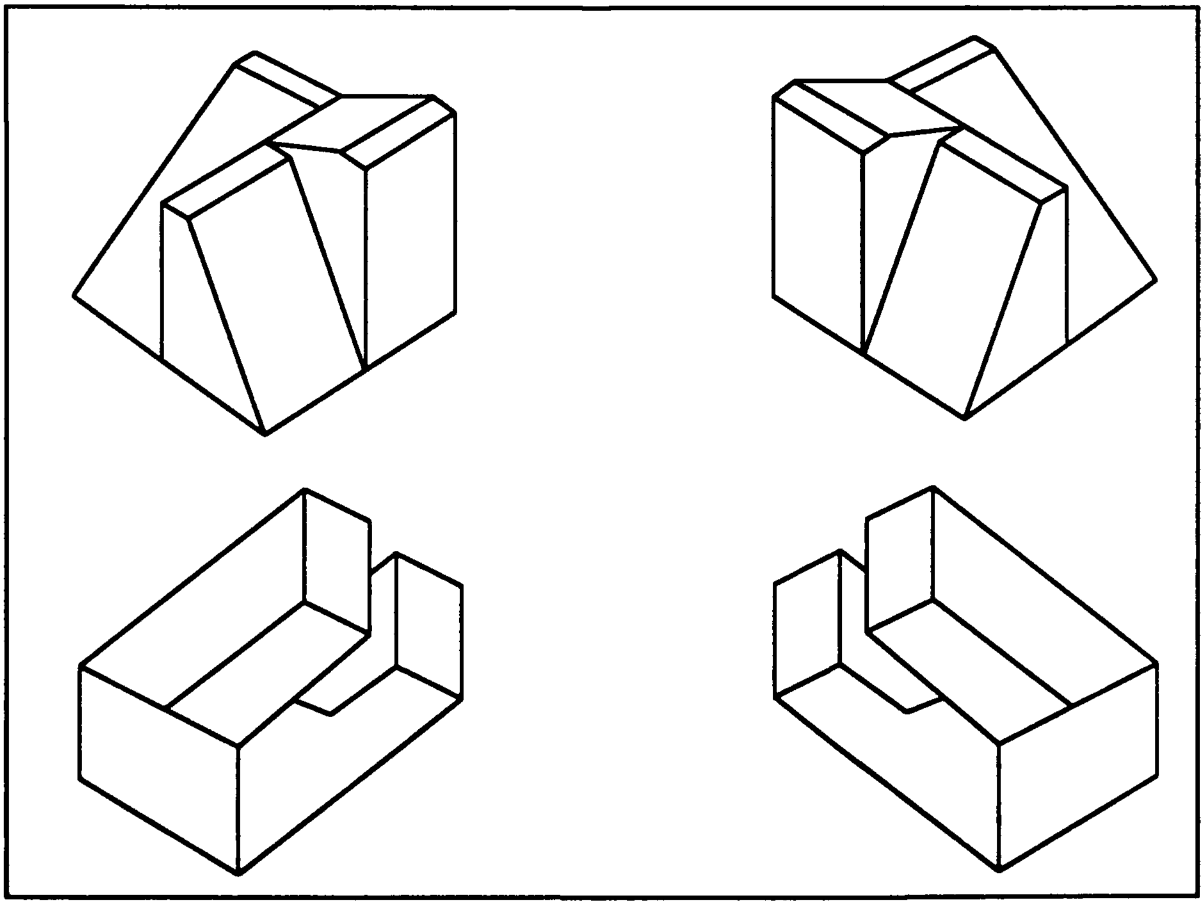
Note. Studied = proportion of studied items called "old" (hit rate). Nonstudied = proportion of nonstudied items called "old" (false alarm rate).

Figure Captions

Figure 1. Examples of target objects used in Experiments 1 and 2. The upper two rows depict a possible (top) and an impossible (bottom) object, shown in both small (right) and large (left) sizes. The lower two rows depict a possible (top) and an impossible (bottom) object, shown in both reflected (right) and standard (left) versions. See text for further explanation.

Figure 2. Summary of results from Experiments 1 and 2. The upper panel displays priming on the object decision task, expressed as percent correct on studied items minus nonstudied items, as a function of object type (possible vs. impossible) and relationship between studied and tested objects (SS = same size; CS = changed size; SV = standard version; RV = reflected version). The lower panel displays recognition, expressed as percent hits minus false alarms, as a function of the same variables. See text for further explanation.





SUMMARY OF PRIMING AND RECOGNITION RESULTS: EXPERIMENTS 1 AND 2